NJ.16-8

NJ.16

Prepared by
Oak Ridge Associated Universities

Prepared for
Division of Fuel Cycle and Material Safety

U.S. Nuclear Regulatory Commission

RADIOLOGICAL SURVEY OF THE W. R. GRACE PROPERTY WAYNE, NEW JERSEY

P. W. FRAME

Radiological Site Assessment Program
Manpower Education, Research, and Training Division

FINAL REPORT

January 1983

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This report is based on work performed under Interagency Agreement DOE No. 40-770-80, NRC Fin. No. A-9093 between the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy. Oak Ridge Associated Universities performs complementary work under contract number DE-AC05-76OR00033 with the U.S. Department of Energy.

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RADIOLOGICAL SURVEY
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INTRODUCTION

In 1948, Rare Earths, Inc., of Wayne, New Jersey, began processing monazite sand to extract thorium and rare earths. The facility was acquired by the Davison Chemical Division of W.R. Grace and Co. in 1957. Processing activities continued until July 1971 when the plant was permanently closed. In 1974 Applied Health Physics, Inc., decontaminated the buildings and the property was released by the Nuclear Regulatory Commission (NRC) for unrestricted use in January 1975. The buildings are currently under lease to, and occupied by, Electro-Nucleonics, Inc.

In January 1981, as part of a review of formerly licensed facilities, the Nuclear Regulatory Commission measured direct radiation levels and radionuclide concentrations in soil on the W.R. Grace property. The results of the survey indicated radiation levels ranging from 10-1000 μR/h and Th-232 concentrations as high as 1200 pCi/g of soil.[1] The State of New Jersey was represented at this survey and requested, through the U.S. Environmental Protection Agency, an aerial radiological survey. In May 1981, the aerial survey was conducted by EG&G. This survey identified elevated radiation levels at 1 m above the surface with average exposure rates greater than 120 μR/h.[2]

In the summer of 1982, the Pequannock Township Health Department performed a radiological survey of the Erie Lackawanna Railroad tracks in response to information that ore destined for W.R. Grace had been unloaded from trains near the Pompton Plains railroad station. This survey and subsequent investigations by the NRC and State of New Jersey identified elevated radiation levels near the intersection of Peck Road and a spur of the Erie Lackawanna Railroad line approximately 200 m north of the railroad station.

At the request of the NRC Division of Fuel Cycle and Material Safety, radiological surveys of the W.R. Grace site, adjacent properties, and the Erie Lackawanna Railroad tracks near Peck Avenue were conducted during July and August 1982, by the Radiological Site Assessment Program of Oak Ridge Associated Universities (ORAU), Oak Ridge, Tennessee. This report represents the findings of those surveys.

A glossary of technical and nuclear terms and schematic representations of the naturally-occurring thorium and uranium radioactive decay series have been presented as Appendices A and B, respectively, to aid in the interpretation of this report.

SITE DESCRIPTION

General

W.R. Grace Property

The W.R. Grace property is located at 868 Black Oak Ridge Road about 2 km east of Pompton Plains and 3 km north of Wayne, in the northeast corner of New Jersey (Figures 1 and 2). The site, shown in Figure 3, occupies approximately 2.6 hectares, most of which is surrounded by a chain link security fence. Two office buildings and a warehouse are the main structures on the site. The eastern and northern sections of the site are wooded and heavy brush and weeds grow along a small drainage stream. This stream enters the property near the southeast corner, flows north, then west. Prior to leaving the fenced-in portion of the site, the stream enters an underground conduit. This conduit carries the water into a tank, where it is mixed with the occasional overflow from an inactive on-site artesian well and the storm sewer system. The water is then discharged to an off-site storm sewer.

The site is bounded by private residences to the north and east, to the south by a property currently used for storage and maintenance of school buses, and by several commercial firms on the west side of Black Oak Ridge Road, across from the W.R. Grace property (see Figure 2).

Erie Lackawanna Railroad

The Erie Lackawanna Railroad runs in a north-south orientation through Pompton Plains in Morris County (see Figure 4). Just north of the point where the railroad crosses Jackson Avenue is the Pompton Plains Railroad Station. Another 200 m further north of the railroad station is the point where Peck Avenue runs into an unused spur of the railroad. The area is a mixture of commercial and residential properties; the nearest residence being approximately 10 m north of Peck Avenue and 20 m west of the spur.

Operations

Between 1948 and 1956 Rare Earths, Inc., processed thorium-containing monazite ore to recover various rare earths and to separate the thorium for use by the Atomic Energy Commission (AEC). Wastes and residues from the processing operations contained less than 5% of the original thorium concentration and were disposed of by burial on the site. Liquid effluents from these processes were neutralized in an on-site treatment plant and combined with the occasional outflow of an on-site artesian well and the small surface drainage stream. The combined effluents were carried, via conduit under the company's north parking lot, to the intersection of Black Oak Ridge Road and Pompton Plains Cross Road where they were released into the storm sewer system (see Figure 5). This storm sewer system flows westerly where it discharges into Sheffield Brook and, eventually, into the Pompton River.

The Davison Chemical Division of W.R. Grace and Co. acquired the plant in 1956 because of the potential uses for purified rare earths and thorium. Between 1957 and 1967, residues and wastes containing most of the thorium from the monazite ores were disposed of by on-site burial. From 1967 to 1971, when processing operations at the site were discontinued, residues were shipped to the W.R. Grace plant in Chattanooga, Tennessee. The Pompton Plains plant was permanently closed in April 1971.

In 1974 Applied Health Physics, Inc., performed a radiological survey of the site and conducted decontamination operations designed to bring the site into compliance with existing regulations permitting release for unrestricted use.[3] In the course of the decontamination operations, contaminated materials and equipment were buried on-site. Portions of the property were then filled or covered with soil and the site was leveled and landscaped.

A fire in May 1977 heavily damaged the main building and destroyed most of the early records, including those containing details concerning the quantities and locations of on-site waste burials. Based on information available in the Applied Health Physics report and conversations with several former employees, suspected burial locations have been identified and are shown on Figure 6.

Several other properties in the Wayne-Pompton Plains area were involved directly or indirectly with the Rare Earths and/or W.R. Grace operations. The property immediately to the south of the W.R. Grace site was formerly leased by W.R. Grace for occasional storage of monazite ore; rail shipments of the ore were unloaded near the Pompton Plains station of the Erie Lackawanna Railroad. Surveys of these two areas were conducted and the findings are included in this report. The drainage stream system (including Sheffield Brook) between the W.R. Grace site and the Pompton River received the treated liquid wastes from facility operations and surface run-off. A survey of this area was conducted earlier and the results have been reported in a separate document.[4]

SURVEY PROCEDURES

Objectives

The survey objectives were as follows:

I. W.R. Grace Site and Adjacent Properties

a. to measure direct radiation levels,
b. to determine the concentrations of radionuclides in surface and subsurface soil,
c. to define locations of burials, and
d. to determine if radionuclides are migrating and/or have migrated from the burial sites.

II. Erie Lackawanna Railroad

a. to measure direct radiation levels, and
b. to determine the concentrations of radionuclides in surface and subsurface soil.

Plan

The survey plans adopted to achieve these objectives included the following activities:

I. W.R. Grace Site and Adjacent Properties

a. Clearance of brush and weeds over the suspected burial areas and the establishment of a 20 m grid system for survey reference.
b. A ground penetrating radar survey to identify the location of the subsurface disturbances and buried objects.
c. Measurement of exposure levels (μR/h) at the surface and at 1 m above the surface at 5 m intervals throughout the W.R. Grace site.

d. Measurement of surface dose rates (μrad/h) at 5 m intervals throughout the W.R. Grace site.

e. Walkover surface scans to identify locations of elevated radiation levels on the W.R. Grace site and adjacent properties.

f. Collection of surface soil samples at grid line intersections and at locations indicated by the walkover scan to have elevated exposure rates.

g. Drilling boreholes and collection of subsurface soil and water samples.

h. Collection of sediment samples from the on-site drainage stream and from the storm drainage sewers.

i. Collection of on-site water samples from the drainage stream and storm sewers.

j. Collection of vegetation samples from various points on the W.R. Grace property.

II. Erie Lackawanna Railroad

a. Measurement of exposure levels (μR/h) 1 m above the ground at 0 m, 5 m, and 10 m distances from either edge of the railroad spur.

b. Walkover surface scans to identify locations of elevated radiation levels.

c. Collection of surface and subsurface soil samples.

d. Collection of vegetation samples.

Procedures

Ground Penetrating Radar Survey

A ground penetrating radar survey of the W.R. Grace property was performed under subcontract by Geo-Centers, Inc. of Newton Upper Falls, MA. The survey technique involves traversing the surface with a transmitter/receiver which emits electromagnetic signal pulses. The reflected signals are recorded and analyzed to identify the locations and depths of buried objects and other subsurface disturbances. The procedure is described in greater detail in the radar survey report included as Appendix C.

Measurement of Direct Radiation Levels

The 20 m grid system established on the W.R. Grace site (see Figure 7) was subdivided into 5 m intervals. At each of these points, exposure rates were measured at the surface and at 1 m above the surface. Measurements were performed with portable NaI(Tl) gamma scintillation ratemeters field calibrated using a pressurized ionization chamber. Beta-gamma dose rates were measured at 1 cm above the surface at each of the locations where exposure rates were measured. These measurements were performed using thin window ($7 mg/cm^2$) "pancake" GM detectors with scaler/ratemeters. To evaluate contributions from non-pentrating radiations, measurements were also made with the detectors shielded with approximately 2 mm of steel. Walkover surface scans of the gridded areas were performed at 1-2 m intervals, using NaI(Tl) gamma scintillation ratemeters. Locations of significantly elevated radiation levels were noted. At locations where the exposure rates were above the range of the NaI(Tl) scintillation ratemeters, measurements were made with an energy compensated GM detector and scaler.

Walkover surface scans were performed at 2-5 m intervals on adjacent properties to the north and south of the W.R. Grace site. Radiation levels were mapped relative to surface features and landmarks.

The Pequannock Township and State of New Jersey surveys identified elevated radiation levels primarily along a 50 m section of a railroad siding just north of Peck Avenue. Several isolated spots were also noted approximately 50 m south of Peck Avenue. The ORAU survey, extending approximately 100 m north and south of Peck Avenue, consisted of walkover surface scans of the railroad tracks. North of Peck Avenue, the siding area was divided into 2 m intervals. At each of these intervals, exposure rates were measured 1 m above the surface, at the edge of the tracks and at 5 and 10 m on either side of the tracks.

Surface Soil Sampling

Surface (0-5 cm) soil samples of approximately 1 kg each were collected at the intersections of 20 m grid lines on the W.R. Grace property. Samples were also collected at selected locations of elevated gamma radiation levels. Efforts were made to include the source of the elevated levels in these samples. Sampling was performed using garden trowels, from which residual soil was cleaned between samples. Locations of on-site surface soil sampling are shown on Figure 8.

Surface soil samples were collected at locations of elevated radiation levels identified on the property south of the W.R. Grace site. Additional surface samples were also obtained at random locations on the adjacent properties. These sampling locations are indicated on Figure 9.

Subsurface Measurements and Sampling

Forty-three boreholes were drilled on the W.R. Grace property. Twenty-three of these were deep holes drilled to ground water depth. Site Engineers of Voorhees, New Jersey, performed the drilling, using 15 cm and 20 cm diameter hollow stem augers. The other twenty boreholes were shallow (approximately 1 m deep) and were drilled by the survey team, using a portable motorized auger.

The ground radar survey results were used to guide the selection of deeper borehole locations to ensure that subsurface utilities were not damaged. Drilling directly into burial trenches was also avoided to prevent damaging trench linings, thus creating potential migration pathways. Shallower boreholes were often located in areas where elevated exposure rates had identified near-surface thorium contamination. Locations of these boreholes are indicated on Figure 10. Shallow boreholes were drilled at two locations on the property south of the site and at eight locations along the railroad. Locations of boreholes on these off-site properties are shown on Figures 9 and 11, respectively.

In boreholes drilled on the W.R. Grace site a collimated NaI(Tl) scintillation probe was lowered into the hole and gamma radiation levels determined at 30 cm intervals. Gamma logging was not performed in the shallow boreholes drilled on the adjacent properties or along the Erie Lackawanna Railroad.

Soil samples were collected at the surface and at several depths in each borehole. The subsurface samples were at depths where gamma logging identified increased direct radiation levels and at additional points to provide a representative profile of subsurface thorium concentrations. Sampling was accomplished by scraping soil from the edges of the borehole using a specially constructed sampling tool or, at greater depths, by use of a split spoon sampler driven through the center of the hollow stem auger.

Because of heavy precipitation which occurred prior to and during the borehole drilling, the water table was unusually high. The pressure caused by the high water table resulted in the water rapidly filling most of the boreholes to within one to two meters of the ground surface. This water was not considered to be representative of the normal ground water conditions on the W.R. Grace site. Permanent monitoring wells have been installed on the property by W.R. Grace. Samples from these wells will be analyzed by ORAU and the results presented in an addendum to this report.

Sediment Sampling

Sediment samples of 1 kg each were collected on the W.R. Grace property from four locations in the drainage stream, from three drainage tiles, and from eight locations in the storm sewer system (see Figure 12). To provide more representative samples, several closely spaced points were sampled at each location and these samples composited.

Vegetation Sampling

Approximately 1 kg of surface vegetation, i.e. grass, weeds, and other ground cover, was collected from five locations on the W.R. Grace site.

These locations are indicated on Figure 12. No vegetation was collected from the adjacent properties. Three vegetation samples were collected from the area along the railroad (see Figure 11).

Water Sampling

Water samples were collected from three locations along the on-site drainage stream and from five locations in the storm sewer system as indicated on Figure 12. Water samples were not obtained from the railroad property or the adjacent properties since no appropriate sources were available for sampling.

Baseline and Background Measurements

Five soil samples, two water samples, and two vegetation samples were collected at locations 0.3 to 10 km from the W.R. Grace site. Direct radiation levels were measured at the locations of the soil samples. Figure 13 indicates the locations of the baseline samples and background measurements which were used for comparison with the other results of this survey.

Equipment and Analytical Procedures

Appendix D contains a list of the major equipment and instrumentation used for this survey. Analytical procedures are described in Appendix E.

RESULTS

Background Radiation Levels and Baseline Concentrations

Background exposure rates measured in the Wayne-Pompton Plains, NJ, area ranged from 6-12 μR/h; surface beta-gamma dose rates ranged from 10-24 μrad/h.

Baseline radionuclide concentrations in soil, vegetation, and water are presented in Tables 1-A and 1-B. The concentrations in these samples are typical of those normally encountered.

W.R. Grace Site

Ground-Penetrating Radar Survey

The report of the ground-penetrating radar survey provided by Geo-Centers, Inc., is presented as Appendix C. This report concluded that the soil on the W.R. Grace property had been subjected to extensive disturbances. Although there were some similarities between the areas of these disturbances and the burial locations as identified by W.R. Grace records, specific numbers and locations of these burial sites did not agree. In addition to the regions of disturbed subsurface soil, numerous individual reflecting targets were observed by the radar scans. These targets were located between the surface and a depth of approximately 2 m, and were randomly distributed, rather than being associated with the subsurface soil disturbances.

Direct Radiation Levels

Exposure rates measured systematically at predetermined grid locations on the W.R. Grace property ranged from 13 to 540 μR/h at 1 m above the surface. The highest levels generally occurred on the portions of the property where burials reportedly are located. However, only a limited correlation was noted between the exposure levels and the burial locations, as identified by site personnel or by the ground-penetrating radar survey. Exposure rates at 1 m decreased to near background levels at the north, east, and west property boundaries. These exposure levels are presented graphically in Figure 14.

The general pattern and levels of the systematically measured surface exposure rates were very similar to those measured at 1 m above the surface. The levels ranged from 9 to 610 μR/h. Many small areas, having significantly elevated contact radiation levels (up to 7710 μR/h), were identified by the walkover surface scan. The locations and exposure rates of some of these areas, which were selected for further surface and subsurface investigations, are shown on Figure 15.

Individual dose rate data are not presented in this report; however, the pattern of these dose rates is in good agreement with the pattern of exposure rates described above. Dose rates (μrad/h) were generally between 1.25 and 2.0 times the surface exposure rates (μR/h). The unshielded probe measurements ranged from 25 to 40 percent higher than the measurements performed with the probe face shielded, indicating a significant dose contribution from beta and low-energy photon radiations. This is consistent with the presence of thorium contamination.

Radionuclide Concentrations in Soil Samples

Radionuclide concentrations in the surface soils collected on the W.R. Grace property are presented in Table 2. The total thorium concentrations (Th-232 + Th-228) ranged from 2.14 pCi/g (sample location S5) to 721 pCi/g (S9) in the samples systematically collected at grid line intersections. The total thorium concentrations in soil collected at locations identified by the walkover survey to have elevated exposure rates (see Figure 8) ranged from 51.2 pCi/g (S58) to 7540 pCi/g (S30). In general, there was a positive correlation between the thorium concentration in the soil and the direct radiation level at the point of sampling. Thorium concentrations in soil samples collected east and north of the drainage stream ranged from 2.14 pCi/g (S5) to 20.0 pCi/g (S4). Surface soil systematically collected on the western portion of the property along Black Oak Ridge Road contained total thorium concentrations ranging from 3.49 pCi/g (S49) to 49.6 pCi/g (S56). However, several isolated spots with elevated exposure rates were identified in this area, and soil samples taken from these locations had thorium concentrations between 51.2 pCi/g (S58) and 832 pCi/g (S54).

Radionuclide concentrations in soil from boreholes on the W.R. Grace site are presented in Table 3. In general, the lowest thorium concentrations were measured in soil from the boreholes drilled east and north of the drainage stream (B1-B9), through the paved areas (B38-B41), and in the lawn near Black Oak Ridge Road (B35, B42, and B43). In the boreholes east and north of the drainage stream, the total thorium concentrations ranged from 2.66 pCi/g (B7) to 11.5 pCi/g (B3) for surface soil and from 1.75 pCi/g (B7) to 9.90 pCi/g (B9) for soil collected from the bottom of the boreholes. Thorium concentrations in soil from boreholes B1-B8 decreased with depth; however, in borehole B9 the concentration increased from 3.50 pCi/g at the surface to 9.90 pCi/g at 1 m. Samples from boreholes B38-B41, drilled in the paved areas, contained thorium concentrations ranging between 3.83 pCi/g (B38) and 5.28 pCi/g (B40) just below the pavement. Concentrations in these boreholes decreased or remained constant down to approximately 2 m. In the boreholes drilled near Black Oak Ridge Road (B35, B42, and B43), the thorium concentrations ranged from 3.06 pCi/g (B35) to 30.4 pCi/g (B43) at the surface and from 2.25 pCi/g at 2 m in B35 to 15.5 pCi/g at 3.6 m in B43.

The maximum thorium concentration measured in the subsurface samples was 30,500 pCi/g. This sample was from the 3.9 m depth in borehole B29. Other boreholes where high subsurface thorium levels were measured were B26 (15,900 pCi/g), B22 (15,400 pCi/g), B15 (9,800 pCi/g), B27 (6,350 pCi/g), and B30 (5,460 pCi/g). Four of these (B22, B15, B27, and B30) were shallow boreholes drilled at locations with notably elevated exposure rates. In each of these boreholes, the thorium concentrations in the soil increased with depth, suggesting that these holes were drilled over areas of buried residues.

The ratios of Ra-226 and U-238 concentrations to total thorium concentrations varied widely in soil samples from the site. Radium-226 concentrations ranged from approximately 0.3% to 32% of the thorium levels; U-238 concentrations ranged from about 0.3% to 35% of the thorium levels. Ratios of U-238 to Ra-226 were also inconsistent. No pattern was noted in these variations. These differences suggest that the materials encountered represent residues from different processes and stages in operations conducted at this site.

Although the Th-232 and Th-228 concentrations generally agreed, several samples exhibited significant differences. For example sample S13 contained 2710 pCi/g of Th-232 but only 1540 pCi/g of Th-228; sample S36, on the other hand, contained 1850 pCi/g of Th-232 and 2300 pCi/g of Th-228. These differences indicate that some of the residues on this site have not yet reached an equilibrium state with the entire thorium decay series.

Radionuclide Concentrations in Sediment Samples

The radionuclide concentrations in sediment samples are presented in Table 4. In the four samples collected from the drainage stream the thorium concentrations ranged from 3.76 pCi/g (sample location D4) to 10.3 pCi/g (D1). No clear pattern was observed in these samples, the highest levels being found in sediment from the stream near its entrance to the W.R. Grace property. Sediment samples D8-D15 collected from the storm sewer system contained thorium levels ranging from 34.3 pCi/g (D8) to 1820 pCi/g (D14). Although the path of this sewer system is not precisely known, a general pattern of increasing concentrations was observed as the system neared the outfall from the W.R. Grace property.

Radionuclide Concentrations in Water Samples

Radionuclide concentrations measured in the water samples from the drainage stream and from the storm sewer system are presented in Tables 5 and 6. Water collected from the drainage stream contained gross alpha concentrations ranging from <3.19 pCi/ℓ* (W3) to 7.21 pCi/ℓ (W1). Gross beta levels in these samples were <5.00 pCi/ℓ. Radium-228 concentrations were <0.18 pCi/ℓ. Radium-226 concentrations ranged from <0.03 pCi/ℓ (W2) to 0.11 pCi/ℓ (W3).

Elevated radionuclide concentrations were present in water from the storm sewer system. Levels ranged from 5.33 pCi/ℓ (D13) to 28.6 pCi/ℓ (D11), gross alpha; 13.4 pCi/ℓ (D13) to 60.8 pCi/ℓ (D11), gross beta;

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* *The "less than" symbol (<) indicates that the concentration is below the detection limits of the analytical technique. Refer to Appendix E for further discussion.*

6.59 pCi/ℓ (D11) to 14.2 pCi/ℓ (D12), Ra-228; and 0.10 pCi/ℓ (D10) to 0.86 pCi/ℓ (D12), Ra-226. The pattern of concentrations in these water samples was consistent with the concentrations in the sediments from the same locations.

Radionuclide Concentrations in Vegetation Samples

Radionuclide concentrations in the five on-site vegetation samples are presented in Table 7. In these samples the Ra-228 concentrations ranged from 1.00 pCi/g (V1) to 3.41 pCi/g (V4) and the Th-228 concentrations from 0.26 pCi/g (V1) to 0.59 pCi/g (V5). All these values are slightly elevated above the baseline sample concentrations. No other radionuclides were present in levels significantly above the baseline concentrations.

Properties Adjacent to the W.R. Grace Site

Surface Radiation Exposure Levels

Elevated radiation levels were noted extending onto the school bus maintenance yard south of the W.R. Grace property. The exposure rates measured at contact with the surface are indicated on Figure 16. Areas with the highest levels were in the vicinity of the concrete loading platform at the northwest corner of the building and near a door on the building's northeast side. Maximum exposure rates at these locations were 250 and 890 μR/h, respectively. Inside the building, elevated direct radiation levels were limited to the northern half of the building and were primarily associated with cracks in the concrete floor.

Exposure rates on the properties to the north, east, and west of the site were in the range of area background levels.

Radionuclide Concentrations in Soil Samples

The radionuclide concentrations in surface soil from the adjacent properties are indicated in Table 8. The three randomly collected soil samples from the private residence north of the W.R. Grace property

(S68-S70) had total thorium concentrations between 1.24 pCi/g (S69) and 2.08 pCi/g (S68). These values are within the range of the baseline samples. Total thorium in the three soil samples (S71-S73) collected in the commercial area immediately west of the W.R. Grace property, ranged between 1.85 pCi/g (S71) and 7.21 pCi/g (S72). The highest concentration was found in sample S72 which was collected from the location (in this area) determined in the walkover survey to have a slightly elevated contact exposure rate of 18 μR/h. The other two samples had concentrations within the range of the baseline samples. South of the W.R. Grace property, in the school bus maintenance yard, the thorium concentrations in the surface soil ranged between 2.32 pCi/g (S81) and 2720 pCi/g (S77). Two samples scraped from the floor inside the north building (S78 and S79) had thorium concentrations of 647 pCi/g and 17.8 pCi/g, respectively.

Two shallow boreholes were drilled in the school bus maintenance yard near the southern boundary of the W.R. Grace site. The radionuclide concentrations in soil from these boreholes are presented in Table 9. The borehole drilled at a location with an elevated surface exposure rate (B44) had a thorium concentation of 3,760 pCi/g in the surface soil. The concentration decreased with depth to baseline levels, i.e. 2.08 pCi/g, at 1 m. The thorium concentration in surface soil from the other borehole, B45, was slightly elevated, 9.30 pCi/g, but the concentrations in subsurface samples were near the baseline range.

Erie Lackawanna Railroad

Direct Radiation Levels

Exposure rates along the Erie Lackawanna Railroad in the vicinity of Peck Avenue measured systematically at 1 m above the ground ranged from 9 to 135 μR/h (see Figure 17). Contact exposure rates are presented in Figure 18. These levels ranged from 7 μR/h to 970 μR/h. (At 1 m above the location with the highest surface exposure rate, i.e. 970 μR/h, the exposure rate was 190 μR/h.) Elevated radiation levels are primarily associated with the west embankment of an unused railroad siding between the spur and a footpath for a distance of 40-50 m north of Peck Avenue.

Three isolated spots with exposure rates of 200 μR/h were also identified adjacent to the railroad spur 70-100 m south of Peck Avenue.

Radionuclide Concentrations in Soil Samples

Radionuclide concentrations in soil samples collected along the Erie Lackawanna Railroad are presented in Table 10. Total thorium concentrations in the surface soil samples ranged from 1.56 pCi/g (B54) to 1280 pCi/g (B46). The lowest levels are in the range of the baseline concentrations; these were in samples (B52-B54), collected from the east side of the railroad tracks. The highest concentrations were in samples from boreholes B46, B47, and B51, drilled at locations having elevated direct radiation levels. The thorium concentrations in these samples were 1280 pCi/g, 813 pCi/g, and 403 pCi/g respectively. In each case the thorium concentrations decreased with depth. Boreholes B48-B50 were drilled in a small mound located between the end of Peck Avenue and the railroad spur. In each of these boreholes, the thorium concentrations increased with depth from near baseline concentrations at the surface to a maximum at a depth of about 0.5 m. The maximum thorium concentrations in boreholes B48, B49, and B50 were 50.4 pCi/g, 42.9 pCi/g, and 9.83 pCi/g respectively. Ratios of Ra-226 to thorium activities in these samples were nearly constant, ranging from about 5% to 8%. Concentrations of Ra-226 to U-238 were approximately equal, suggesting that the contamination in this area is due to unprocessed monazite sand.

Radionuclide Concentrations in Vegetation Samples

The radionuclide concentrations in vegetation samples (V6-V8) collected from the vicinity of the Erie Lackawanna Railroad are presented in Table 11. In all cases, the radionuclide concentrations were within the range of the baseline samples.

DISCUSSION

This survey identified thorium contamination in soil on the W.R. Grace site, the adjacent property south of that site, and a section of the Erie Lackawanna Railroad in neighboring Pompton Plains. Elevated direct radiation levels are associated with this contamination. The contamination on the W.R. Grace property appears to be process residues, consistent with previous uses of monazite sands and on-site burials of wastes. Contamination on the adjacent property south of the W.R. Grace site and the Erie Lackawanna Railroad appears to be unprocessed monazite sand, originating from handling or storage of the sands on those properties.

W.R. Grace Site

Contamination on the W.R. Grace and Co. site apparently originated from on-site storage and shallow land burial of ores, wastes, residues, and contaminated equipment from previous operations. The relatively high thorium surface contamination levels in some locations and the findings of the ground-penetrating radar survey suggest that the burials were not necessarily at well defined locations and that buried wastes may have been disturbed and eventually spread over the eastern portion of the property.

Borehole sampling and measurements at suspected burial locations indicated higher concentrations in the subsurface soil than in the surface soil. Thorium concentrations in soil samples collected east and north of the drainage stream (well away from the burial areas) and along the western property boundary were slightly elevated. Thorium concentrations in surface and subsurface soil, collected near the south property boundary also were elevated.

Due to the extensive disturbance of soil on the property, lack of agreement between site personnel and ground-penetrating radar results concerning the burial locations, and because of intentional avoidance of drilling into suspected burial trenches, it was not possible to estimate with reasonable accuracy the total volume and activity of the on-site wastes.

Direct radiation levels on almost the entire portion of the site where burials are suspected exceeded 60 μR/h. Access to areas of highest radiation levels is restricted and the site is posted with radiation warning signs.

Buildings on the site were surveyed prior to termination of the W.R. Grace license and levels were verified recently by the NRC Region 1 office. These buildings were found to meet the NRC criteria for release for unrestricted use and therefore were not included in the ORAU survey.

Radionuclide levels in the sediment and water from the drainage stream are elevated but do not indicate that this is a significant migration pathway. The general slope of the property is away from the stream. Surface run-off from areas of contaminated soil into this stream is, therefore, very limited.

All of the sediment samples from the on-site storm sewer contained elevated thorium concentrations; all of the water samples collected from the storm sewer had gross alpha levels above those in baseline samples. The high thorium levels in some of these sediment samples indicate a concentration by placer action. These findings and the elevated radiation levels and surface soil concentrations along other surface drainage pathways on the W.R. Grace site suggest transport by water run-off has been and continues to be a significant mode of migration.

Ground water sampling was complicated by heavy rains. Permanent monitoring wells have been installed and the results of sampling from these wells will be provided as an addendum to this report.

Adjacent Properties

Only one soil sample from the adjacent properties north and west of the site had a thorium level exceeding the range of the baseline samples. Thorium concentrations in surface soil from the adjacent property, south of the W.R. Grace site, exceeded baseline levels. Thorium contamination is also present on the floor of one of the buildings. This contamination probably resulted from occasional use of the property for monazite sand storage.

Surface run-off from the W.R. Grace site may also have contributed to this contamination. Thorium concentrations in the subsurface soil samples, collected on this property, were only slightly higher than those in baseline samples.

Surface exposure rates on the northern portion of this property also exceed area background levels. Highest levels are located along the boundary nearest the W.R. Grace property and in several small isolated areas adjacent to and inside the building once used for monazite sand storage.

Erie Lackawanna Railroad

Elevated surface soil concentrations of thorium are present along the section of the Erie Lackawanna Railroad included in this survey. Subsurface soil samples, collected at locations of higher direct radiation levels, also contain thorium concentrations exceeding the baseline soil levels. The contamination is believed to be in the form of unprocessed monazite sand, which was reportedly unloaded at this location. Elevated direct radiation levels, associated with the thorium contamination, are present along the track north of Peck Avenue, and there are several small isolated areas of elevated surface radiation 50-75 m south of Peck Avenue.

Radiation Guidelines

Guidelines for levels of radiation and radioactive materials in the environment are established by federal regulatory agencies such as the Nuclear Regulatory Commission (NRC) and Environmental Protection Agency (EPA). These guidelines are usually based on conservative factors of land use and occupancy, potential intake by inhalation and ingestion, biological retention times, relative hazard of the radionuclide, and potentially exposed population group. Such guidelines are, therefore, for highly restrictive situations that may not be representative of the actual conditions at a specific site. For this reason, these federal guidelines are often used as target criteria with site-specific limits established on case-by-case basis. Guidelines for concentrations of radionuclides in soil have not been specifically developed for the W.R. Grace site or other properties included in this survey.

The Nuclear Regulatory Commission's Standards for Protection Against Radiation (10CFR20) establishes limits of radiation dose for occupational radiation workers and for the general public. An individual in the general public may receive an annual radiation dose of 500 millirem.[5] Assuming continual exposure, i.e. 168 h/wk, this allowable annual dose is equivalent to an average exposure rate of approximately 60 μR/h.

SUMMARY

At the request of the Nuclear Regulatory Commission, the ORAU Radiological Site Assessment Program conducted a radiological survey of the W.R. Grace site in Wayne, New Jersey. Surveys of properties adjacent to the W.R. Grace site and a section of the Erie Lackawanna Railroad in neighboring Pompton Plains were also performed.

The findings indicate extensive thorium contamination in soil on portions of the W.R. Grace site. Radionuclide concentrations in the sediment and water collected from the on-site storm sewer indicate this system is a possible pathway for off-site migration of contamination. Migration appears to be by placer movement, rather than by leaching of radionuclides from the residues.

A portion of the property (including one of the buildings) bordering the W.R. Grace site on the south and a section of the Erie Lackawanna Railroad also have elevated thorium concentrations in soil and radiation levels. The contamination on these two properties appears to be primarily unprocessed ore. Other properties adjacent to the W.R. Grace site do not have thorium concentrations or direct radiation differing significantly from the range of area baseline and background levels.

Permanent monitoring wells are being installed to measure radionuclide concentrations in ground water on the W.R. Grace site. Results of these measurements are not completed and will be provided as an addendum to this report.

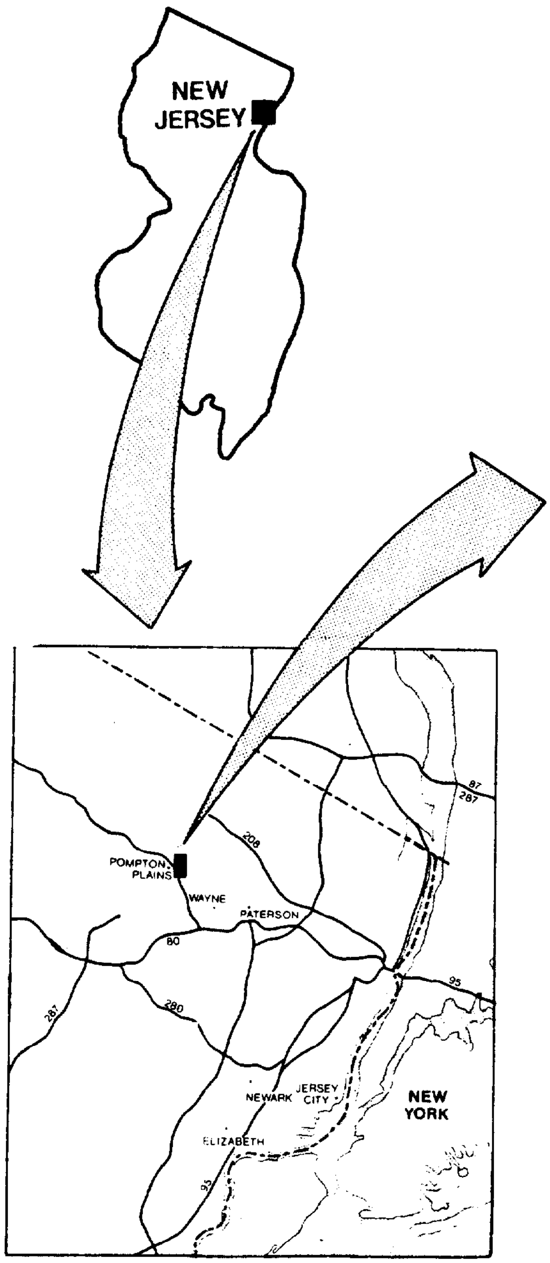


FIGURE 1. Map of Northeastern New Jersey Indicating the Location of the W.R. Grace Property.

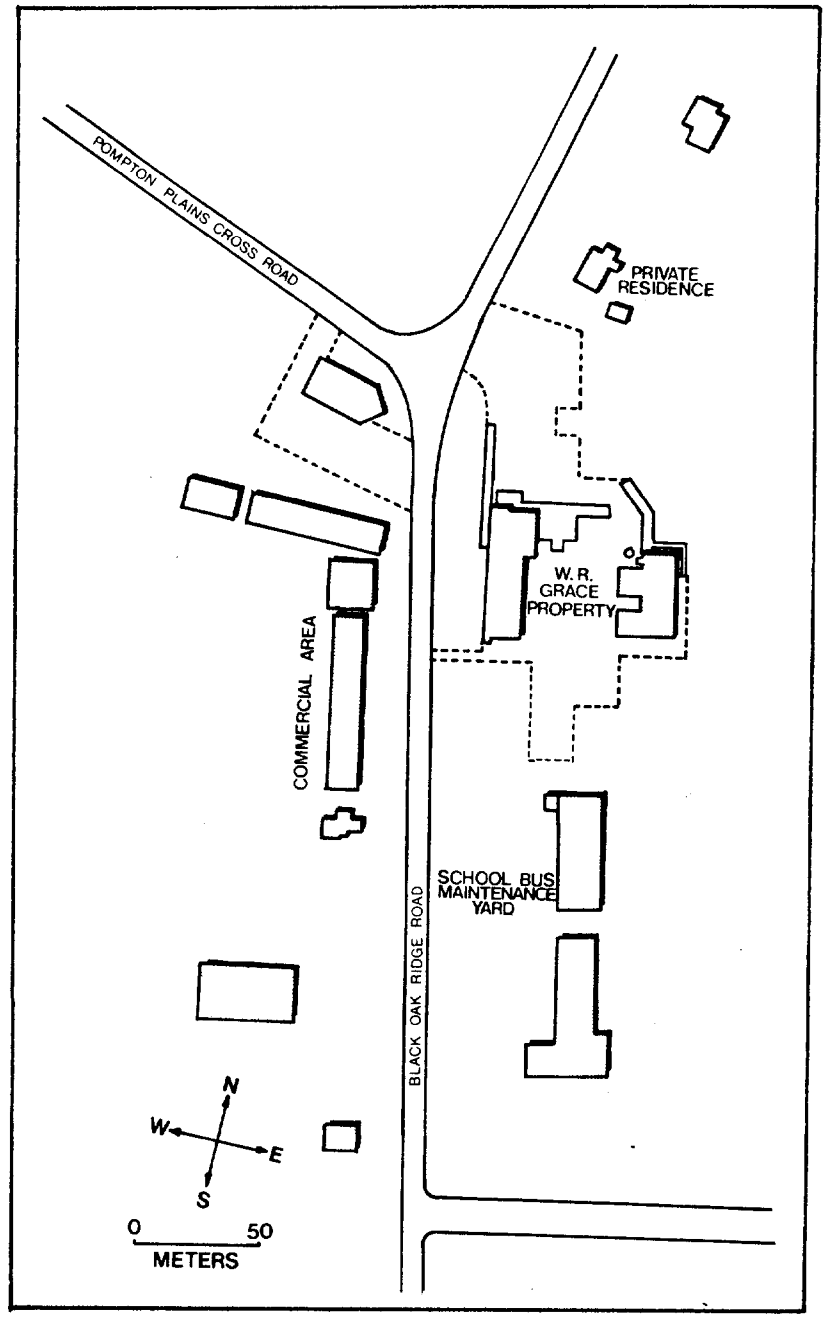


FIGURE 2. Portion of Wayne, New Jersey, Indicating the Locations of the W.R. Grace Property and Adjacent Properties. (Dotted lines indicate paved areas.)

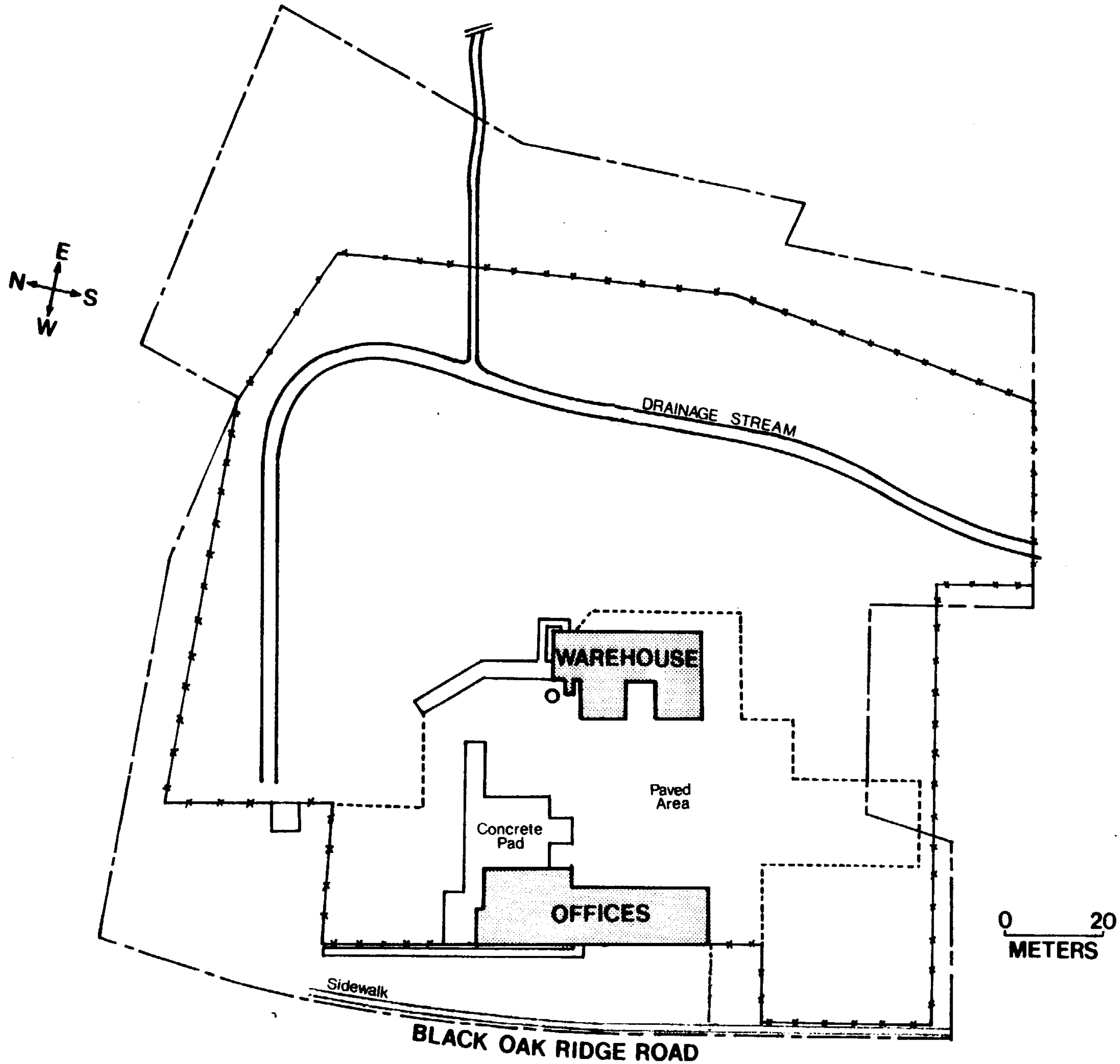


FIGURE 3. Plan View of the W.R. Grace Property.

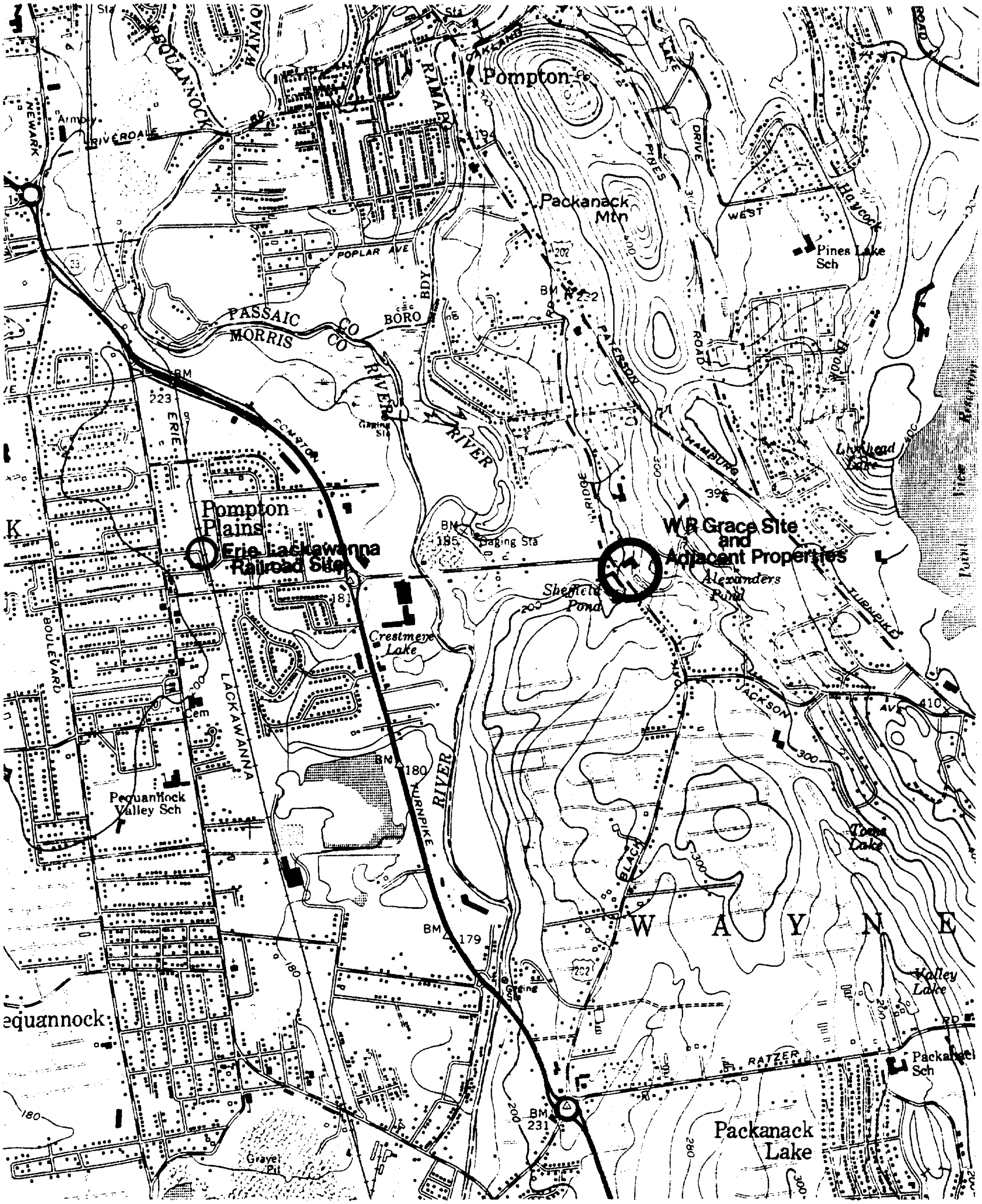


FIGURE 4. Map of the Wayne-Pompton Plains, New Jersey, Area Indicating the Location of the W.R. Grace Site and the Erie Lackawanna Railroad Site.

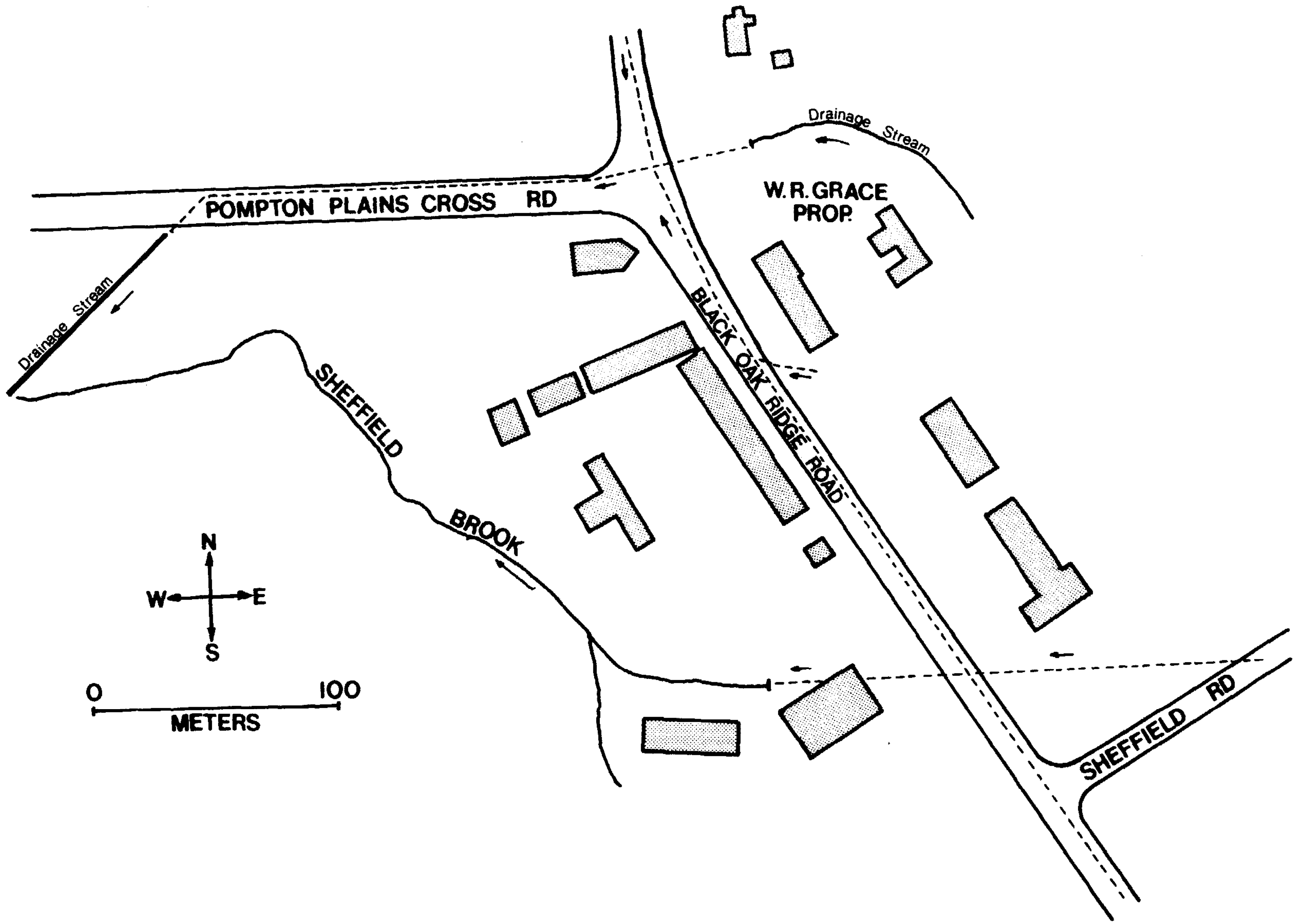
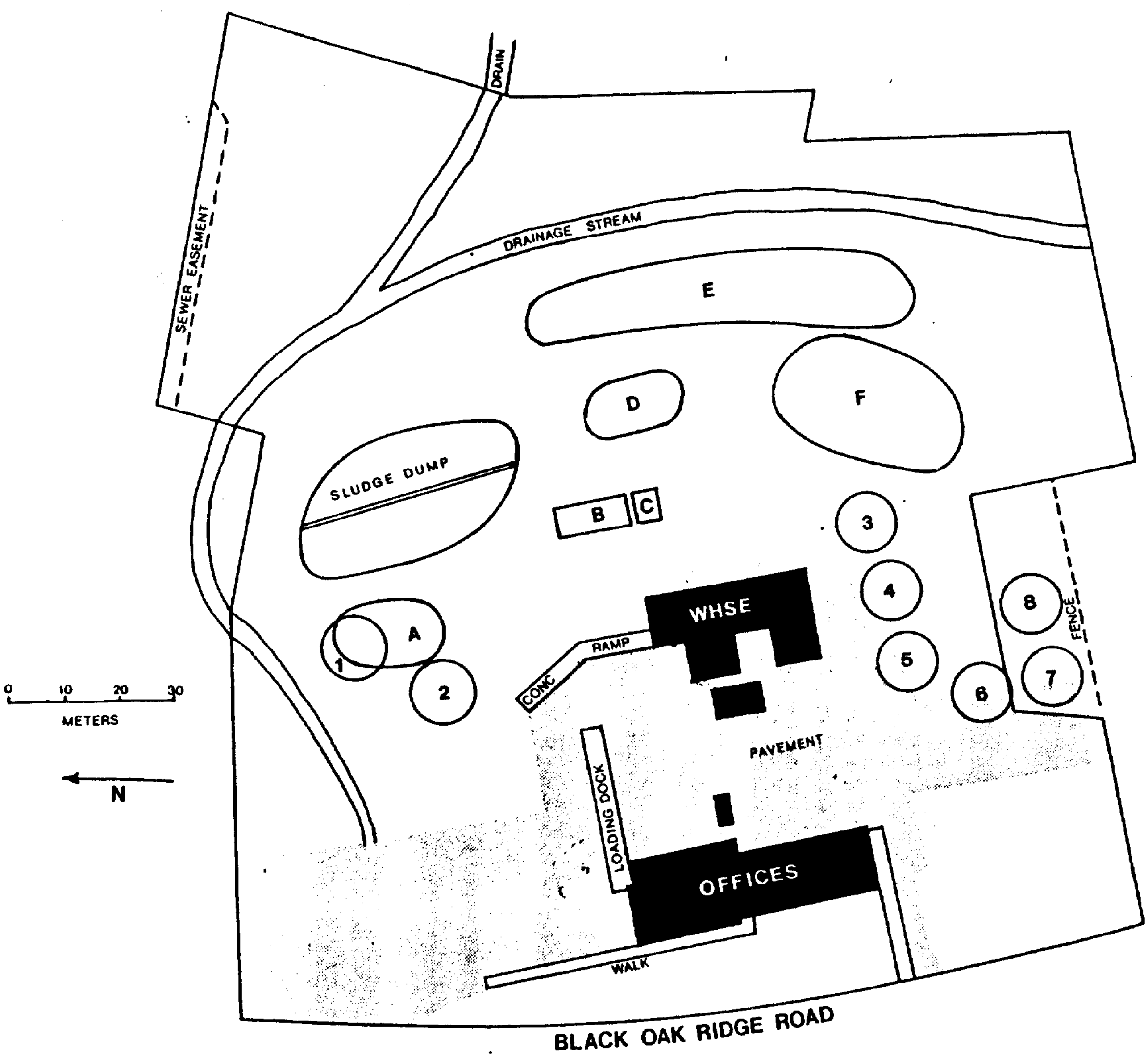


FIGURE 5. Plan View of the Storm Drainage System Servicing the W.R. Grace Site.



A=Reworked Sludges
B=Yttrium Concentrate
C=Thorium Hydroxide
D=Waste Treatment Disposal
E=Ore Tailings and Gangue
F=Yttrium and Silica Sludges

1-8 = Circular Holes Filled April-June 1974 with debris and contaminated equipment resulting from decontamination of buildings.

FIGURE 6. Suspected Burial Locations on the W. R. Grace Property.

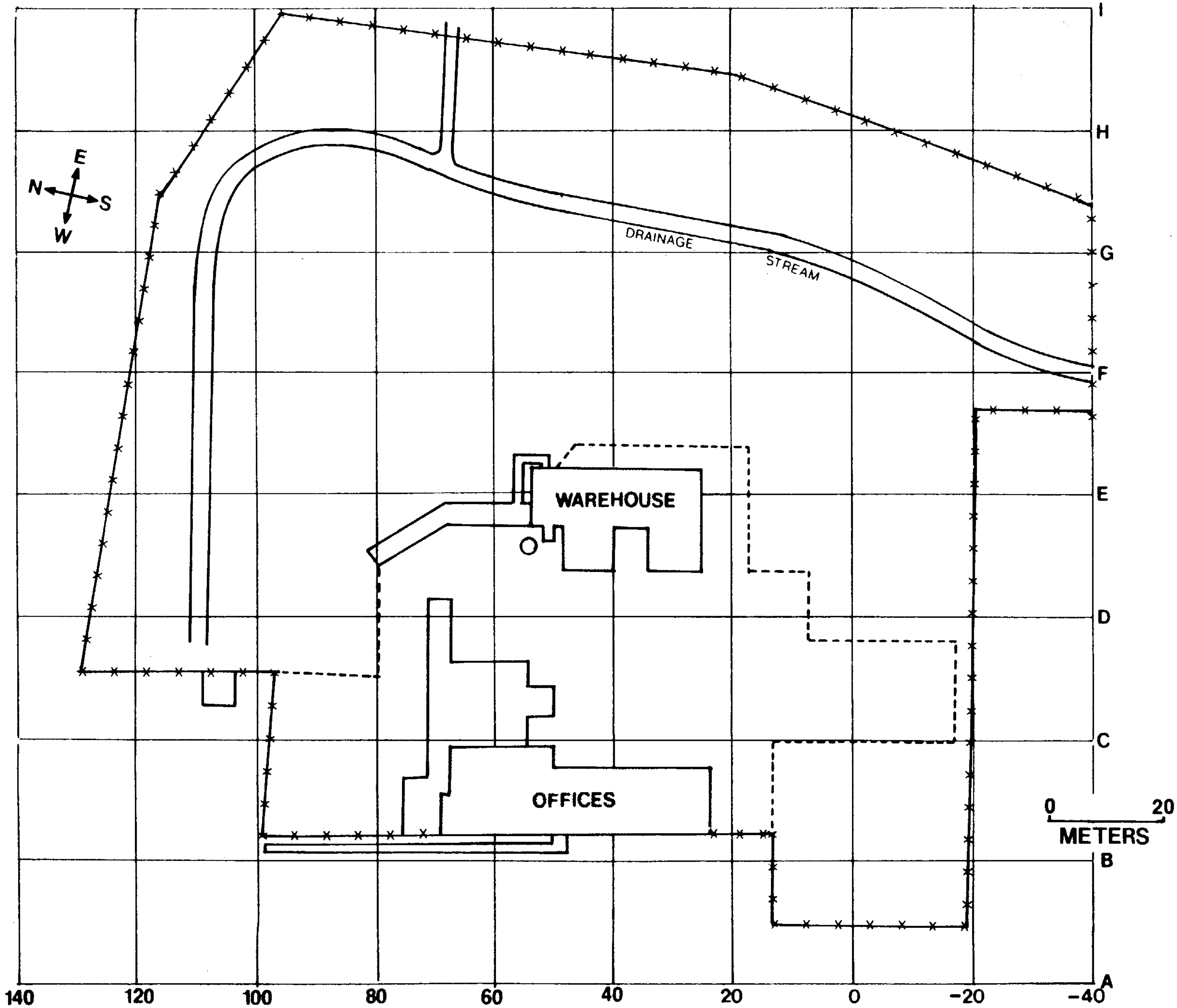


FIGURE 7. Grid System Established for Survey Reference.

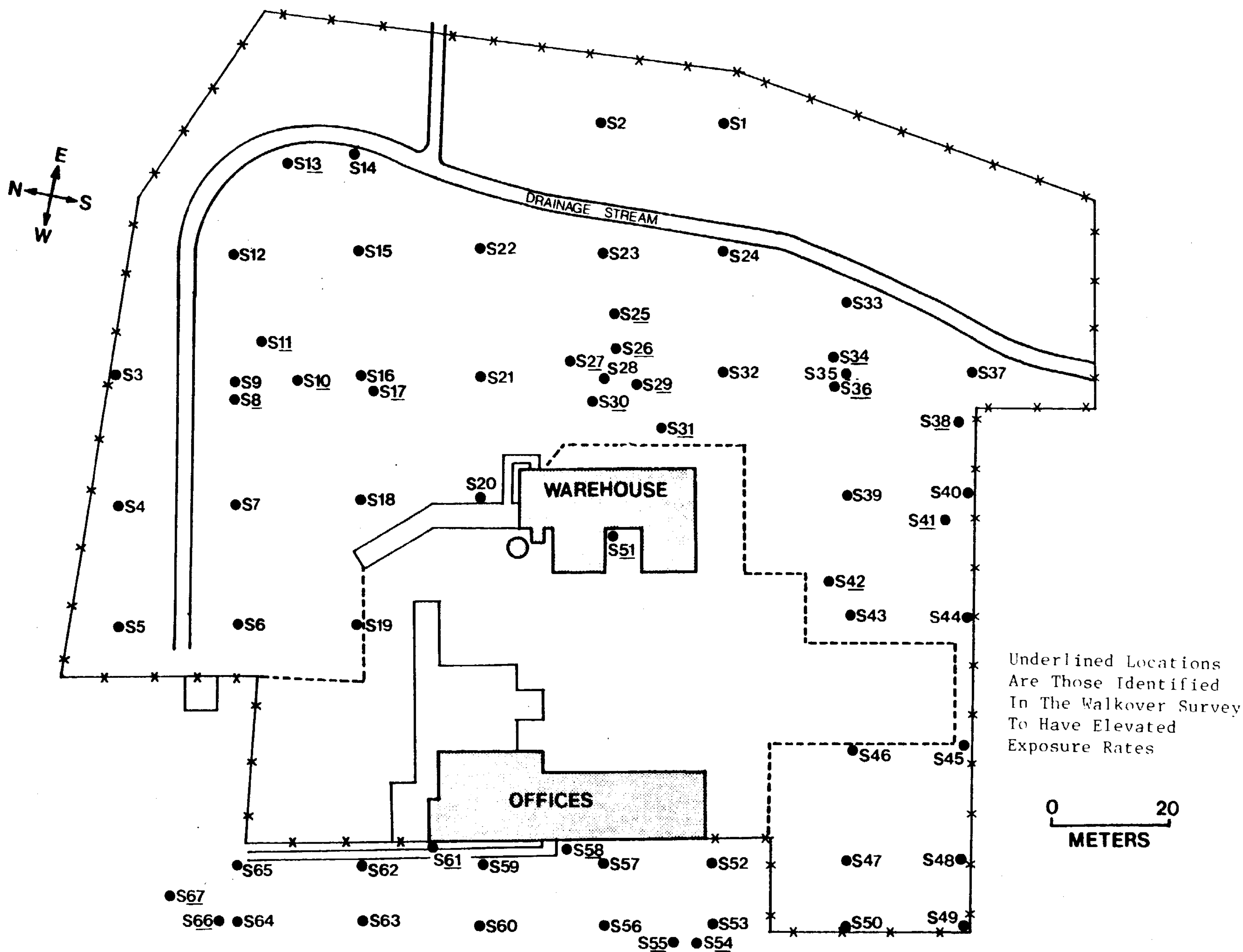


FIGURE 8. Surface Soil Sampling Locations on the W.R. Grace Property.

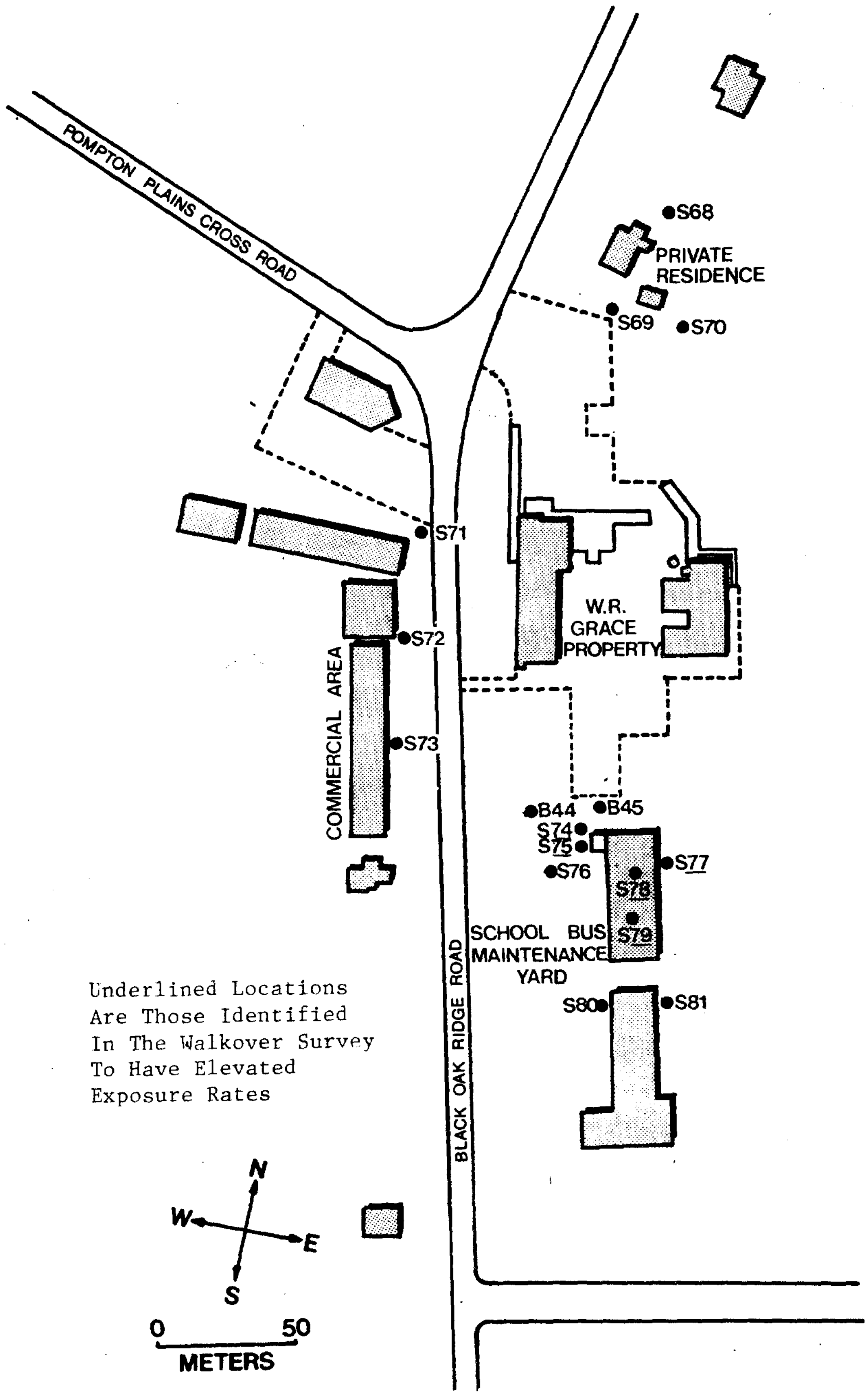


FIGURE 9. Surface Soil Sampling and Borehole Locations Adjacent to the W.R. Grace Property.

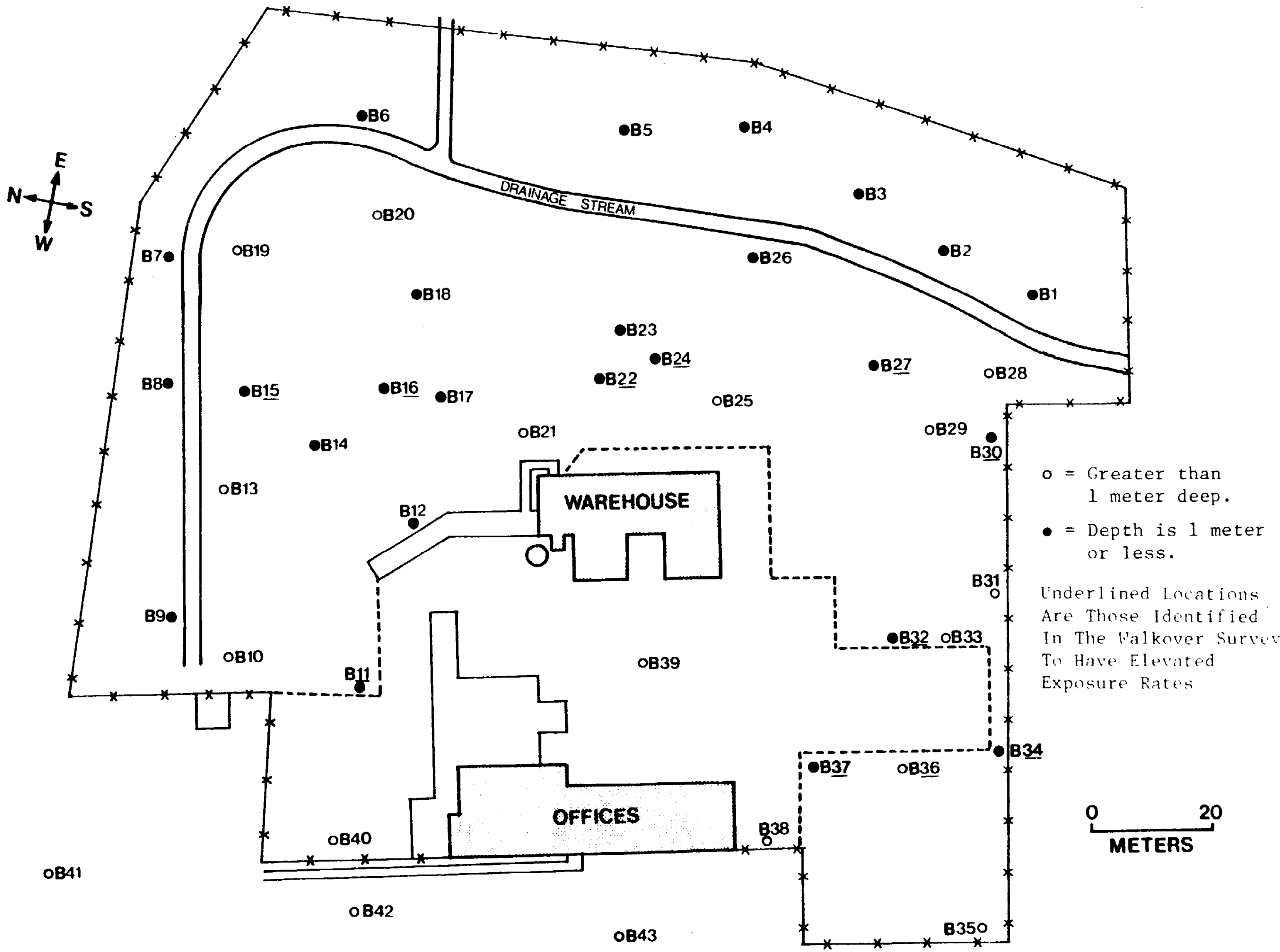


FIGURE 10. Borehole Locations on the W.R. Grace Property.

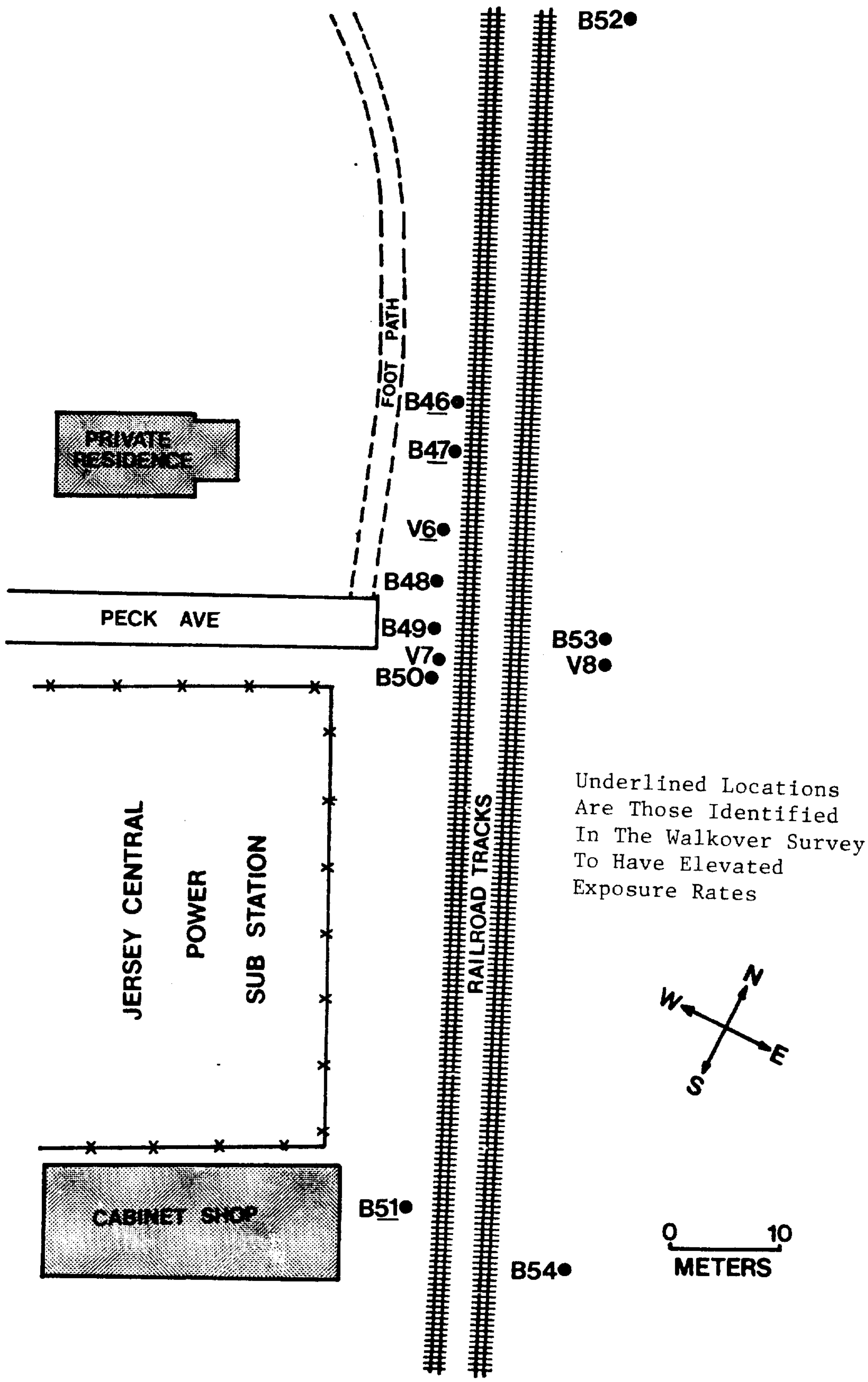


FIGURE 11. Borehole and Vegetation Sampling Locations Along the Erie Lackawanna Railroad in Pompton Plains, NJ.

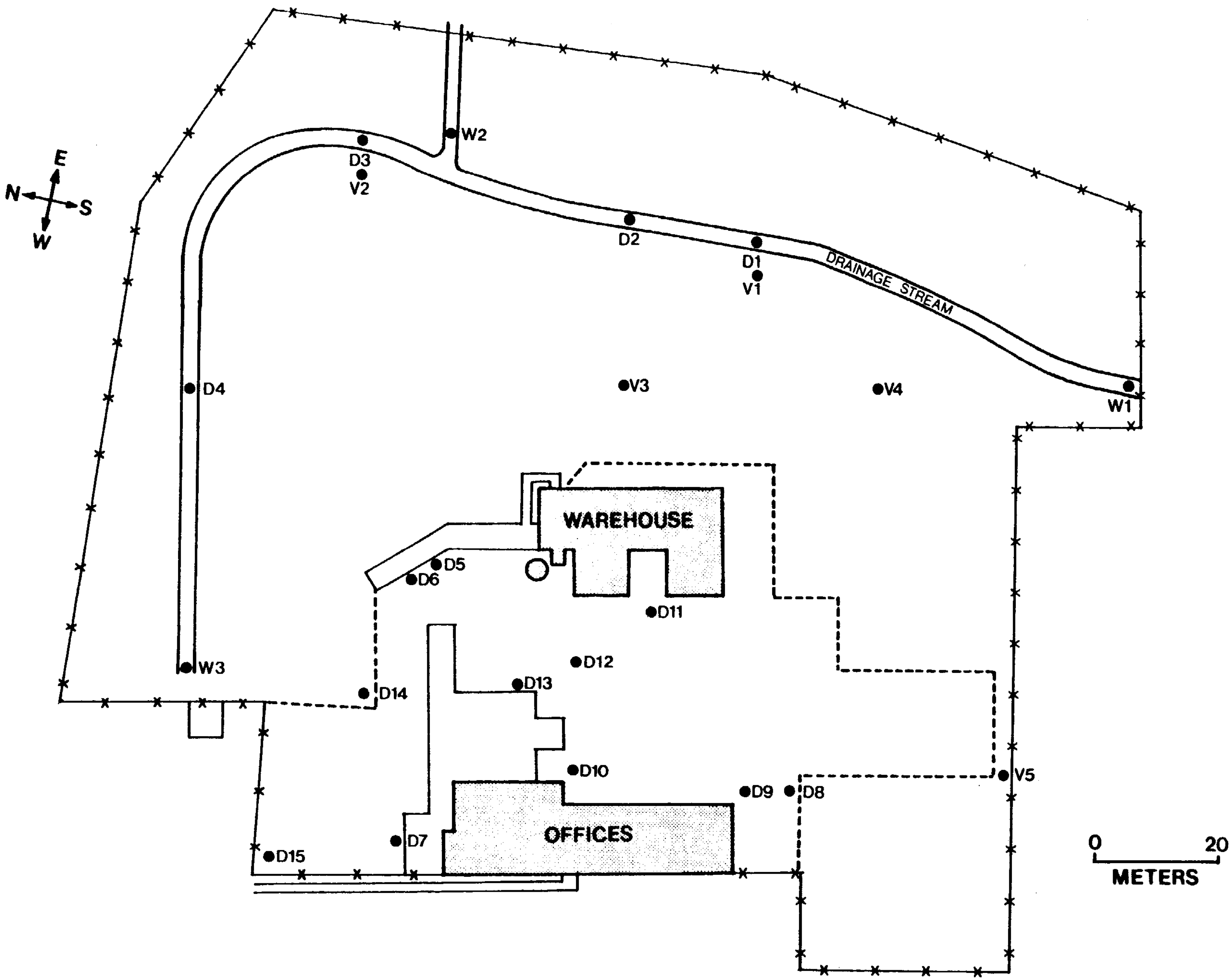


FIGURE 12. Sediment, Water, and Vegetation Sampling Locations on the W.R. Grace Property.

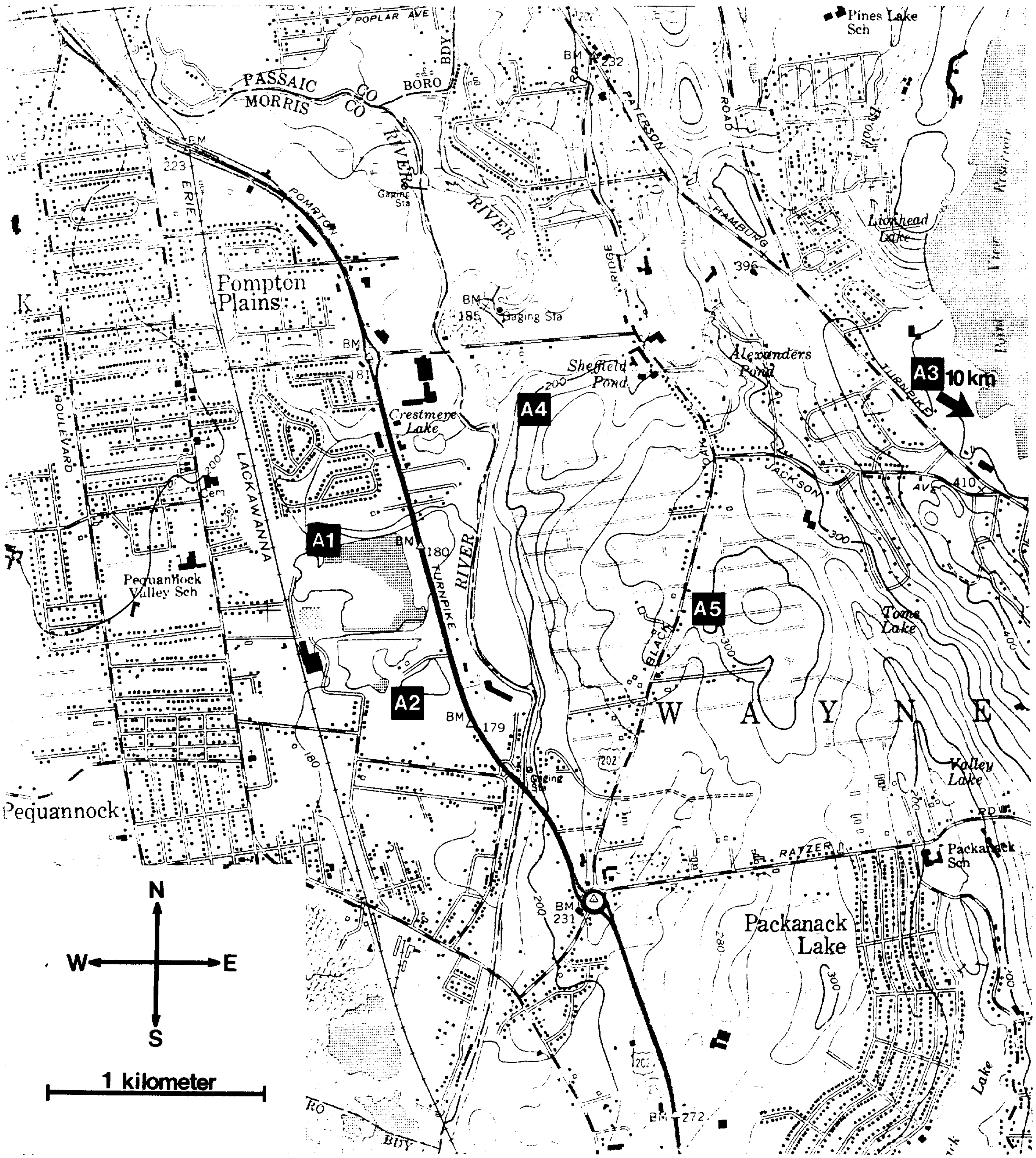


FIGURE 13. Locations of Background Measurements and Baseline Samples in the Wayne-Pompton Plains Area.

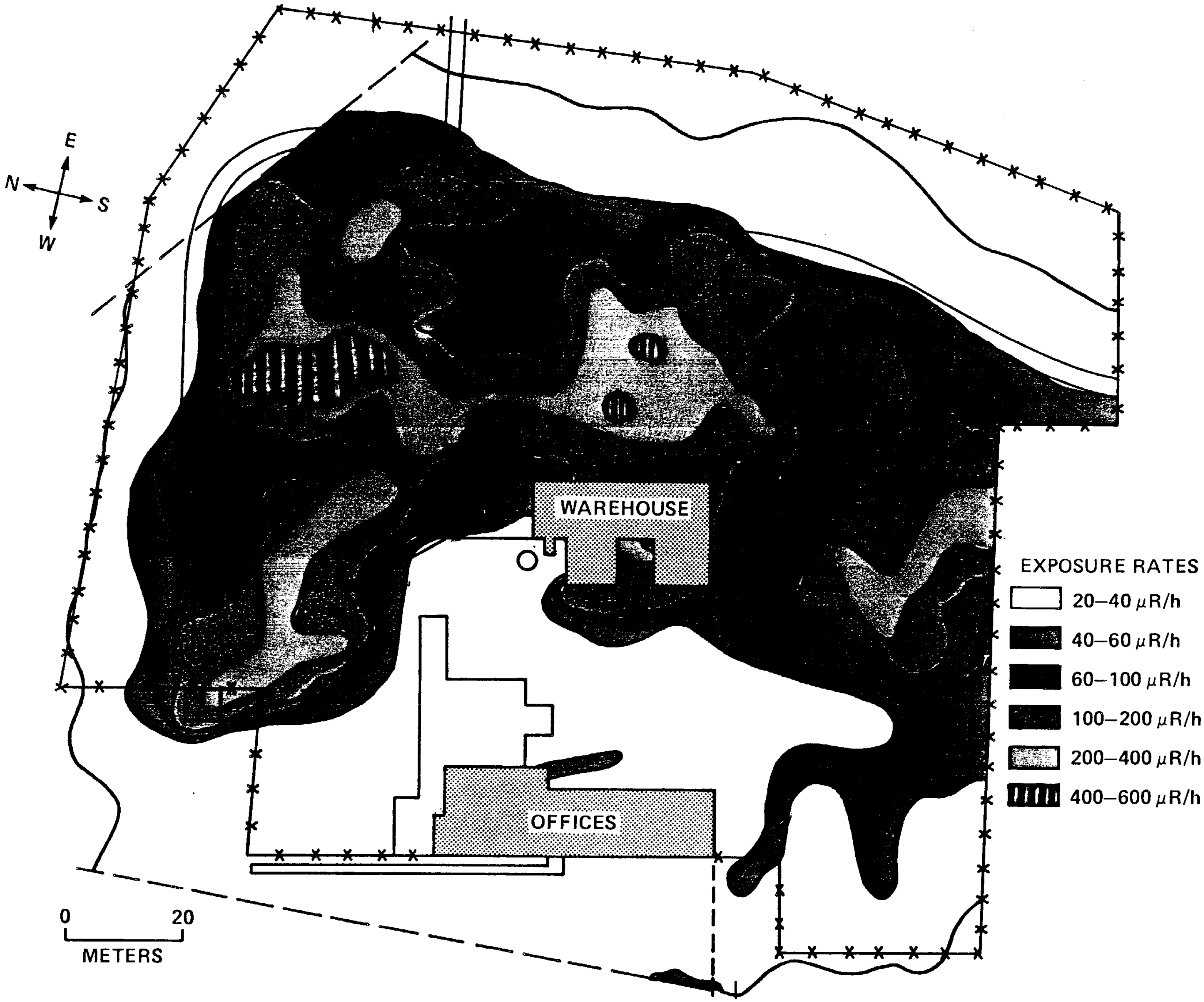


FIGURE 14. Exposure Rates (μR/h) at 1 m Above the Surface on the W.R. Grace Property.

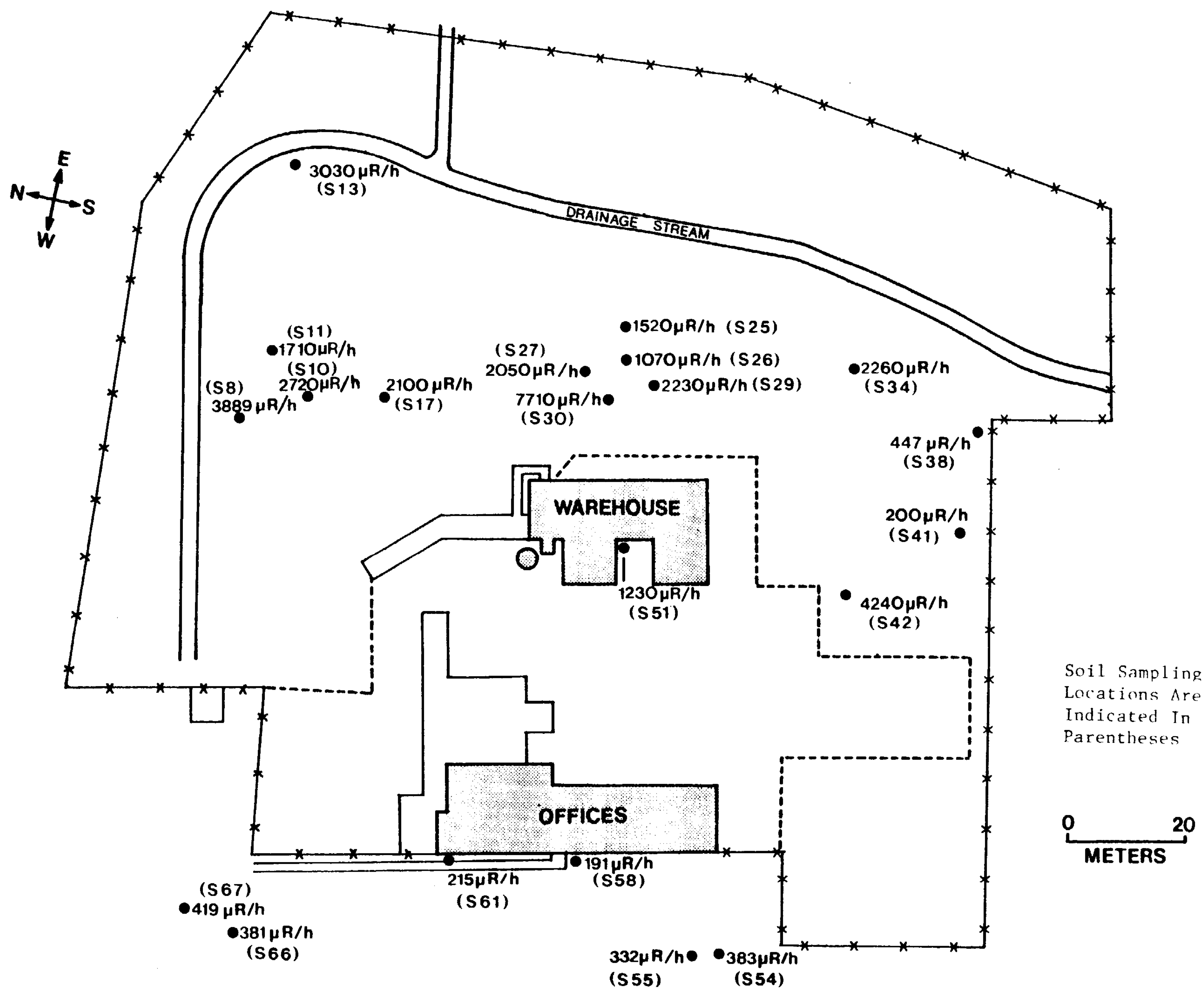


FIGURE 15. Surface Exposure Rates at Sampling Locations of Biased Surface Soil Samples.

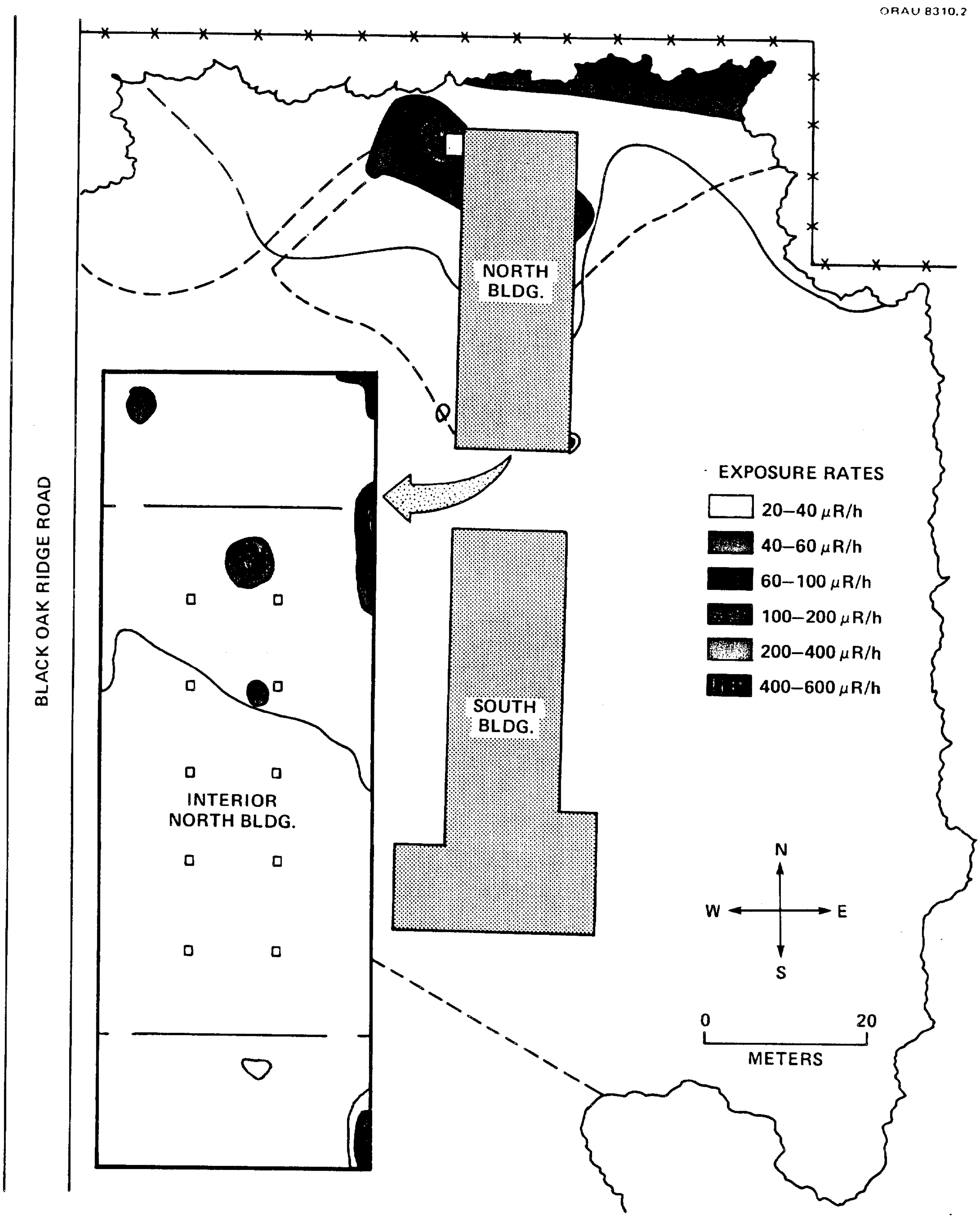


FIGURE 16: Surface Exposure Rates (μR/h) on the School Bus Maintenance Yard.

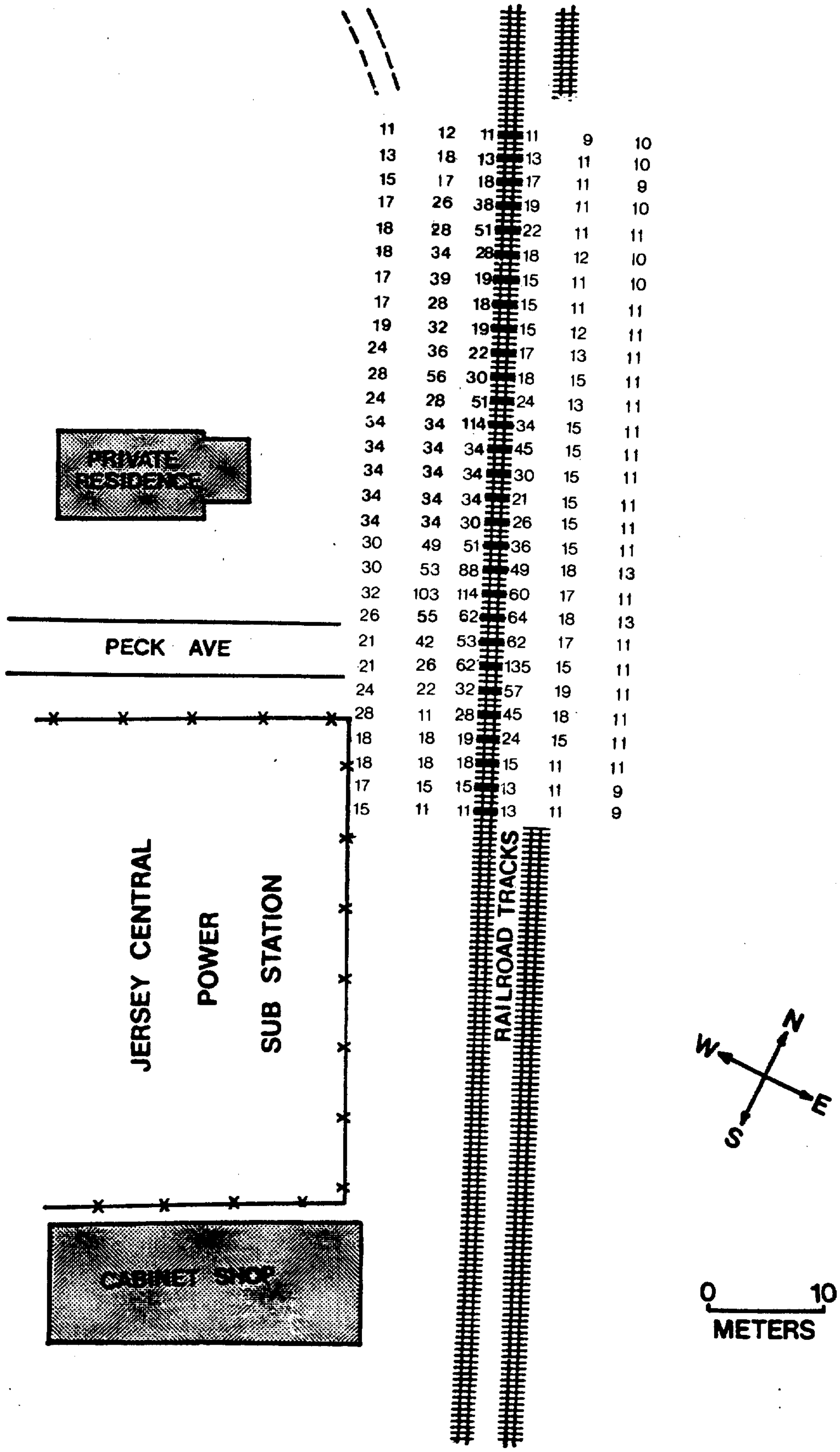


FIGURE 17. Exposure Rates (μR/h) at 1 m Above the Surface Along the Erie Lackawanna Railroad in Pompton Plains.

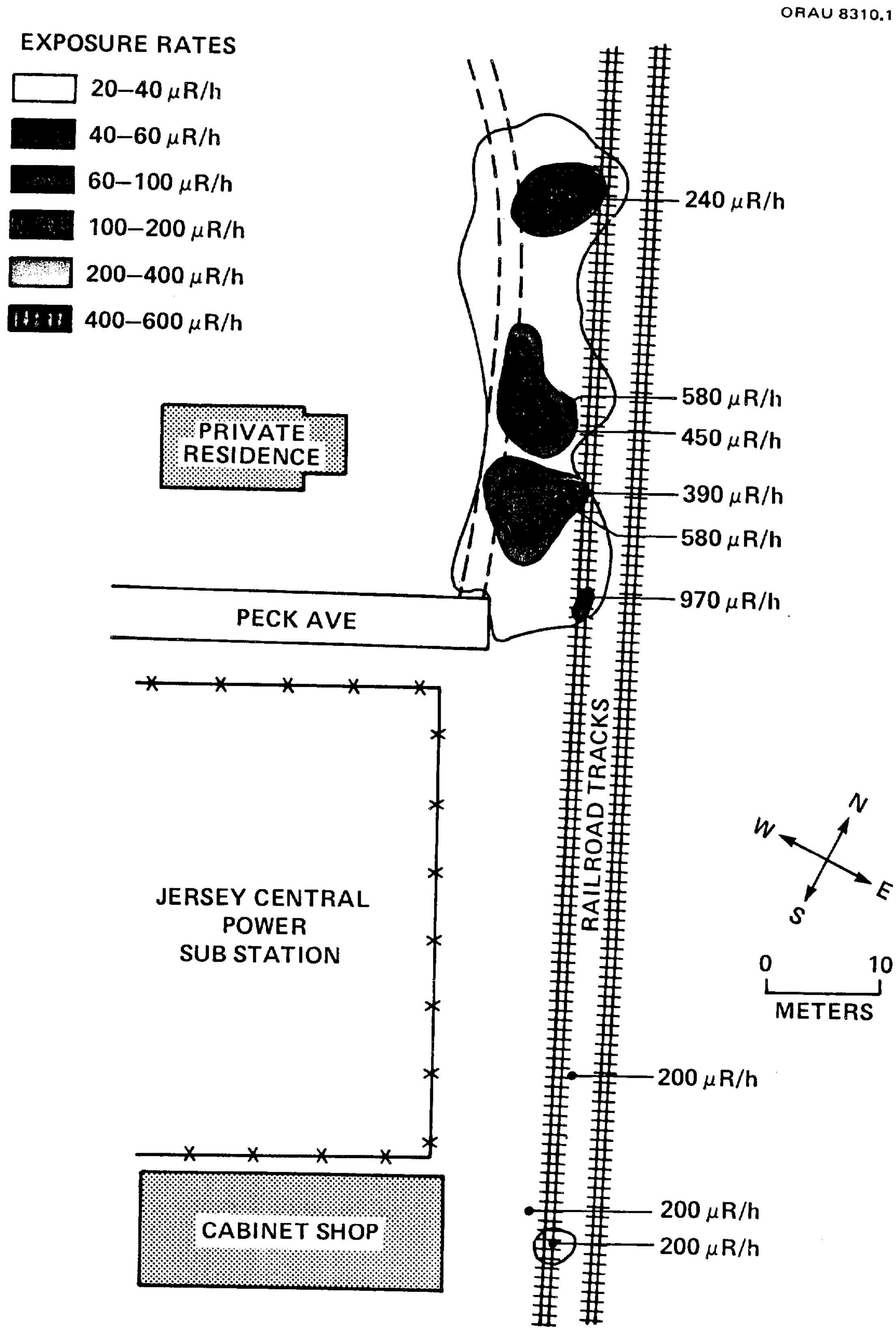


FIGURE 18. Surface Exposure Rates (μR/h) Along the Erie Lackawanna Railroad in Pompton Plains.

TABLE 1-A

RADIONUCLIDE CONCENTRATIONS IN BASELINE SOIL AND VEGETATION SAMPLES

Sample Location[a]	Depth (cm)	Radionuclide Concentrations (pCi/g)			
		Th-232 (Ra-228)	Th-228	Ra-226	U-238
Soil:					
A1 - P.V. Park	surface	0.51 + 0.23[b]	0.58 ± 0.27	0.47 ± 0.15	<MDA[c]
	30	0.72 ± 0.22	0.80 ± 0.21	0.47 ± 0.22	"
	60	0.69 ± 0.21	0.69 ± 0.21	0.49 ± 0.13	"
	90	0.45 ± 0.33	0.54 ± 0.17	0.50 ± 0.16	"
A2 - McDonald Park	surface	0.69 ± 0.25	0.56 ± 0.23	0.45 ± 0.17	"
	30	1.00 ± 0.25	0.71 ± 0.30	0.58 ± 0.20	"
	60	0.56 ± 0.23	0.59 ± 0.18	0.37 ± 0.12	"
	90	0.72 ± 0.24	0.66 ± 0.21	0.40 ± 0.19	"
A3 - Orth Ave.	surface	1.36 ± 0.33	1.60 ± 0.31	1.13 ± 0.26	"
	30	1.17 ± 0.23	1.39 ± 0.19	1.34 ± 0.17	"
	60	1.18 ± 0.24	1.31 ± 0.19	1.11 ± 0.17	"
A4 - Farmingdale Rd.	surface	0.92 ± 0.32	1.00 ± 0.26	1.12 ± 0.25	"
	30	1.00 ± 0.29	1.21 ± 0.28	1.05 ± 0.21	"
A5 - Black Oak Ridge Road	surface	0.85 ± 0.30	0.70 ± 0.21	0.85 ± 0.20	"
	30	0.91 ± 0.29	0.73 ± 0.22	0.65 ± 0.18	"
Vegetation:					
A1 - P.V. Park		<0.10	0.29 ± 0.13	<0.06	"
A2 - McDonald Park		0.39 ± 0.18	0.31 ± 0.14	0.21 ± 0.15	"

[a] Refer to Figure 13.
[b] Error is 2σ based on counting statistics.
[c] MDA levels for U-238 ranged between 2 and 5 pCi/g.

TABLE 1-B

RADIONUCLIDE CONCENTRATIONS IN BASELINE WATER SAMPLES

Sample Location[a]	Radionuclide Concentrations in Water (pCi/l or x 10^{-9} μCi/ml)									
	Gross Alpha	Gross Beta	Th-228	Th-230	Th-232	Ra-226	Ra-228	U-234	U-235	U-238
A1 P.V. Park	0.95 ± 1.20[b]	<1.3	0.10 ± 0.07	0.07 ± 0.03	<0.05	0.09 ± 0.08	<0.63	0.19 ± 0.03	<0.05	0.13 ± 0.03
A2 McDonald Park	<2.28	<3.6	<0.05	<0.05	<0.05	---[c]	---	0.12 ± 0.03	<0.05	0.09 ± 0.02
A6 City Water	<1.56	<3.7	<1	<1	<1	<0.07	1.12 ± 0.65	<1	<1	<1

[a] Refer to Figure 13.
[b] Error is 2σ based on counting statistics only.
[c] Dash indicates analysis not performed.

TABLE 2

RADIONUCLIDE CONCENTRATIONS IN ON-SITE
SURFACE SOIL SAMPLES

Sample Location[a]	Radionuclide Concentrations (pCi/g)			
	Th-232 (Ra-228)	Th-228	Ra-226	U-238
S1	2.17 ± 0.42[b]	2.06 ± 0.36	0.68 ± 0.25	<3.81
S2	3.00 ± 0.55	3.35 ± 0.46	1.09 ± 0.28	<3.08
S3	1.95 ± 0.39	1.88 ± 0.31	0.91 ± 0.24	<3.46
S4	10.4 ± 0.8	9.59 ± 0.65	1.29 ± 0.35	<5.52
S5	1.18 ± 0.42	0.96 ± 0.26	0.60 ± 0.18	<3.22
S6	69.5 ± 2.4	69.1 ± 2.1	4.01 ± 0.90	33.4 ± 0.9
S7	41.4 ± 1.6	36.7 ± 1.3	4.82 ± 0.67	28.3 ± 0.8
S8[c]	2250 ± 20	1670 ± 10	13.2 ± 5.1	423 ± 2
S9	368 ± 5	353 ± 5	10.9 ± 1.8	114 ± 1
S10	2240 ± 20	1830 ± 20	39.0 ± 6.1	173 ± 2
S11	1920 ± 20	1450 ± 10	48.5 ± 7.0	401 ± 2
S12	73.8 ± 2.0	69.0 ± 1.7	3.05 ± 0.75	<9.42
S13	2710 ± 20	1540 ± 10	13.6 ± 6.5	109 ± 1
S14	23.5 ± 1.1	19.7 ± 0.9	0.85 ± 0.42	<5.40
S15	21.6 ± 1.0	18.7 ± 0.9	1.31 ± 0.39	<5.56
S16	66.3 ± 2.1	54.5 ± 1.8	5.10 ± 0.93	34.5 ± 0.8
S17	1010 ± 10	729 ± 8	18.2 ± 4.1	172 ± 1
S18	269 ± 4	214 ± 3	10.2 ± 1.4	<17.7
S19	77.2 ± 2.1	69.0 ± 1.7	4.99 ± 0.79	10.7 ± 0.7
S20	24.8 ± 1.4	24.7 ± 1.0	1.03 ± 0.41	3.13 ± 0.50
S21	74.0 ± 2.1	70.8 ± 1.7	7.46 ± 0.42	16.2 ± 0.7
S22	33.1 ± 1.5	29.1 ± 1.0	1.16 ± 0.44	<6.41
S23	16.6 ± 1.1	17.5 ± 1.0	2.62 ± 0.52	<6.06
S24	9.69 ± 0.89	8.74 ± 0.77	3.94 ± 0.48	<6.57
S25	1190 ± 10	931 ± 8	360 ± 7	<70.5
S26	1330 ± 10	1440 ± 10	710 ± 6	61.0 ± 1.0
S27	1200 ± 10	899 ± 13	87.2 ± 5.9	90.7 ± 1.1
S28	206 ± 3	171 ± 3	15.0 ± 1.3	33.4 ± 0.8
S29	1630 ± 30	1760 ± 20	586 ± 15	116 ± 1
S30	4500 ± 30	3040 ± 20	159 ± 11	144 ± 1
S31	1000 ± 10	869 ± 5	114 ± 4	61.1 ± 0.8
S32	63.5 ± 1.9	58.0 ± 1.6	5.02 ± 0.77	<0.97
S33	9.83 ± 0.89	9.51 ± 0.70	1.56 ± 0.03	<5.29
S34	2740 ± 30	2700 ± 30	646 ± 12.	35.7 ± 0.9
S35	109 ± 3	115 ± 2	13.2 ± 1.1	<12.0
S36	1850 ± 20	2300 ± 20	591 ± 12	47.7 ± 0.9
S37	18.5 ± 1.6	18.9 ± 0.65	1.29 ± 0.35	<5.52
S38	558 ± 5	479 ± 5	56.0 ± 2.6	<28.7
S39	101 ± 2	98.8 ± 2.0	9.85 ± 1.00	16.0 ± 0.8
S40	32.6 ± 1.6	31.6 ± 1.2	3.62 ± 0.62	<7.98
S41	216 ± 4	253 ± 3	32.1 ± 1.6	<17.7
S42	2220 ± 30	2090 ± 30	705 ± 16	75.4 ± 1.2
S43	82.7 ± 2.3	84.8 ± 2.0	11.6 ± 1.0	<11.4

TABLE 2, cont.

RADIONUCLIDE CONCENTRATIONS IN ON-SITE
SURFACE SOIL SAMPLES

Sample Location[a]	Radionuclide Concentrations (pCi/g)			
	Th-232 (Ra-228)	Th-228	Ra-226	U-238
S44	94.8 ± 2.7	88.5 ± 2.1	4.21 ± 0.89	14.6 ± 0.7
S45	41.4 ± 1.7	41.7 ± 1.5	6.30 ± 0.80	<9.22
S46	172 ± 3	170 ± 2	21.0 ± 1.3	<15.4
S47	3.65 ± 0.61	3.42 ± 0.56	0.92 ± 0.31	<3.76
S48	2.79 ± 0.48	3.10 ± 0.42	0.99 ± 0.24	<3.15
S49	1.63 ± 0.42	1.86 ± 0.38	0.86 ± 0.22	<3.63
S50	1.81 ± 0.42	1.89 ± 0.36	0.81 ± 0.24	<3.30
S51	212 ± 3	211 ± 3	20.5 ± 1.4	14.5 ± 0.6
S52	5.57 ± 0.59	5.89 ± 0.51	0.84 ± 0.28	<3.61
S53	3.81 ± 0.51	4.35 ± 0.45	0.96 ± 0.29	<4.07
S54	438 ± 7	394 ± 6	14.7 ± 2.5	37.4 ± 0.8
S55	547 ± 5	431 ± 4	15.5 ± 2.2	39.2 ± 0.9
S56	26.2 ± 1.2	23.4 ± 1.0	4.86 ± 0.56	<6.76
S57	6.60 ± 0.70	7.56 ± 0.61	0.71 ± 0.30	<4.17
S58	26.5 ± 1.2	24.7 ± 1.0	1.33 ± 0.42	<5.61
S59	4.95 ± 0.58	4.88 ± 0.53	0.77 ± 0.31	<4.29
S60	10.6 ± 0.8	8.19 ± 0.62	1.10 ± 0.34	<4.28
S61	101 ± 2	104 ± 2	15.3 ± 1.1	<11.9
S62	6.63 ± 0.71	6.59 ± 0.50	0.97 ± 0.33	<3.97
S63	7.41 ± 0.64	6.86 ± 0.55	0.88 ± 0.29	<3.65
S64	7.57 ± 0.82	7.87 ± 0.62	1.16 ± 0.34	<4.41
S65	9.78 ± 0.79	8.88 ± 0.66	1.31 ± 0.37	<5.34
S66	207 ± 3	192 ± 3	8.31 ± 1.32	42.0 ± 0.9
S67	321 ± 4	269 ± 4	8.63 ± 1.52	52.8 ± 44.5

[a] Refer to Figure 7.
[b] Error is 2σ based on counting statistics only.
[c] Underlined sample locations are those identified during the walkover survey to have elevated exposure rates.

TABLE 3

RADIONUCLIDE CONCENTRATIONS IN ON-SITE BOREHOLE SOIL SAMPLES

Sample Location[a]	Depth (meters)	Radionuclide Concentrations (pCi/g) Th-232 (Ra-228)	Th-228	Ra-226	U-238
B1	Surface	4.36 ± 0.59[b]	4.22 ± 0.48	1.20 ± 0.25	<4.67
	0.5	1.12 ± 0.34	1.18 ± 0.24	0.62 ± 0.19	<2.62
	0.75	0.96 ± 0.25	1.09 ± 0.23	0.88 ± 0.18	<2.53
B2	Surface	5.41 ± 0.65	5.34 ± 0.51	1.34 ± 0.31	<4.51
	0.5	1.14 ± 0.36	0.96 ± 0.25	0.74 ± 0.16	<2.59
	1.0	0.96 ± 0.26	0.93 ± 0.26	0.70 ± 0.17	<1.86
B3	Surface	5.31 ± 0.73	6.17 ± 0.65	2.29 ± 0.48	<5.45
	0.5	1.44 ± 0.31	1.35 ± 0.29	1.01 ± 0.20	1.49 ± 0.52
	0.75	1.05 ± 0.29	1.05 ± 0.23	0.64 ± 0.17	<2.69
B4	Surface	3.45 ± 0.67	3.76 ± 0.57	1.30 ± 0.34	<4.73
	0.5	0.99 ± 0.24	1.10 ± 0.21	0.72 ± 0.17	<2.62
B5	Surface	4.19 ± 0.66	4.40 ± 0.53	1.39 ± 0.36	1.54 ± 0.57
	0.5	1.54 ± 0.42	2.07 ± 0.32	1.14 ± 0.24	<2.76
B6	Surface	1.67 ± 0.30	1.73 ± 0.26	0.88 ± 0.20	<2.81
	0.5	1.43 ± 0.37	1.45 ± 0.27	1.35 ± 0.22	<2.34
	1.0	1.32 ± 0.32	1.38 ± 0.31	1.03 ± 0.20	<3.56
B7	Surface	1.46 ± 0.49	1.20 ± 0.33	0.79 ± 0.23	<1.93
	0.5	0.89 ± 0.25	0.87 ± 0.27	0.69 ± 0.18	<2.93
	0.75	0.84 ± 0.27	0.91 ± 0.21	0.59 ± 0.16	<2.61
B8	Surface	1.47 ± 0.38	1.41 ± 0.29	1.12 ± 0.24	<3.17
	0.5	1.62 ± 0.43	1.68 ± 0.35	1.63 ± 0.28	<2.95
	1.0	1.53 ± 0.37	1.45 ± 0.35	1.12 ± 0.24	<3.38
B9	Surface	1.91 ± 0.33	1.59 ± 0.31	0.65 ± 0.21	<3.22
	0.5	2.38 ± 0.44	2.43 ± 0.35	0.93 ± 0.23	<3.33
	1.0	4.98 ± 0.51	4.92 ± 0.48	0.89 ± 0.26	5.54 ± 0.52
B10	Surface	39.7 ± 1.3	30.0 ± 1.0	2.17 ± 0.54	<6.95
	0.5	31.9 ± 1.2	25.3 ± 0.9	1.15 ± 0.38	16.6 ± 0.5
	2.4	1.90 ± 0.34	1.54 ± 0.30	0.79 ± 0.20	18.4 ± 0.6
B11[c]	Surface	258 ± 3	227 ± 3	14.4 ± 1.4	29.5 ± 0.7
	0.5	196 ± 3	181 ± 3	8.35 ± 1.26	35.0 ± 0.9
	0.75	191 ± 3	182 ± 3	7.08 ± 1.19	53.0 ± 0.9

TABLE 3, cont.

RADIONUCLIDE CONCENTRATIONS IN ON-SITE
BOREHOLE SOIL SAMPLES

Sample Location	Depth (meters)	Radionuclide Concentrations (pCi/g)			
		Th-232 (Ra-228)	Th-228	Ra-226	U-238
B12	Surface	56.8 ± 1.6	45.5 ± 1.3	3.60 ± 0.61	11.1 ± 0.6
	0.5	10.6 ± 0.9	8.64 ± 0.60	2.29 ± 0.35	15.4 ± 0.6
B13	Surface	13.8 ± 0.9	12.8 ± 0.8	2.57 ± 0.49	8.8 ± 0.6
	0.5	4.41 ± 0.53	4.78 ± 0.44	1.24 ± 0.27	<4.16
	1.0	5.08 ± 0.55	4.84 ± 0.52	0.91 ± 0.24	<3.93
	2.0	1.20 ± 0.28	1.43 ± 0.27	0.80 ± 0.21	<2.62
B14	Surface	10.9 ± 1.0	11.2 ± 0.6	2.79 ± 0.41	9.19 ± 0.55
	0.5	6.45 ± 0.58	5.73 ± 0.48	2.32 ± 0.34	4.77 ± 0.51
	1.0	6.80 ± 0.58	5.86 ± 0.48	2.59 ± 0.34	<4.84
B<u>15</u>	Surface	3970 ± 30	4000 ± 30	296 ± 16	910 ± 4
	0.5	702 ± 22	785 ± 15	477 ± 11	559 ± 3
	1.0	4650 ± 30	5150 ± 30	782 ± 19	653 ± 3
B<u>16</u>	Surface	1750 ± 10	1860 ± 10	930 ± 9	205 ± 1
	0.5	565 ± 8	637 ± 9	370 ± 6	185 ± 1
	1.0	366 ± 7	392 ± 5	171 ± 4	123 ± 1
B17	Surface	6.21 ± 0.60	6.02 ± 0.57	1.41 ± 0.32	41.0 ± 0.8
	0.5	33.4 ± 1.6	30.5 ± 1.1	11.8 ± 0.7	30.2 ± 0.6
	1.0	88.6 ± 2.1	55.7 ± 1.5	5.02 ± 0.79	40.1 ± 0.8
B18	Surface	23.5 ± 1.1	18.0 ± 0.9	4.41 ± 0.55	40.4 ± 0.7
	0.5	17.8 ± 1.0	15.3 ± 0.8	4.32 ± 0.45	26.2 ± 0.6
	1.0	36.0 ± 1.3	23.8 ± 1.0	4.32 ± 0.56	16.4 ± 0.6
B19	Surface	13.1 ± 0.80	10.4 ± 0.6	1.53 ± 0.32	<4.71
	0.5	<2.59	<0.75	<1.17	<42.9
	1.0	9.37 ± 0.82	10.0 ± 0.7	1.69 ± 0.39	10.5 ± 0.5
	1.5	3.45 ± 0.41	3.21 ± 0.35	1.02 ± 0.22	3.46 ± 0.50
	2.0	1.23 ± 0.29	1.23 ± 0.23	0.83 ± 0.19	<2.60
	2.5	1.09 ± 0.28	1.06 ± 0.22	0.81 ± 0.21	<2.39
	4.8	17.9 ± 1.0	17.1 ± 0.9	1.51 ± 0.41	4.62 ± 0.50
B20	Surface	195 ± 3	135 ± 2	5.83 ± 0.97	<12.3
	0.5	990 ± 11	933 ± 9	27.4 ± 4.6	<68.7
	1.7	842 ± 8	617 ± 8	16.2 ± 3.1	248 ± 85
B21	Surface	206 ± 3	212 ± 4	14.0 ± 1.5	39.6 ± 0.8
	0.3	406 ± 7	376 ± 6	14.6 ± 2.5	<34.0
	1.7	616 ± 9	355 ± 5	<1.26	<39.3

TABLE 3, cont.

RADIONUCLIDE CONCENTRATIONS IN ON-SITE BOREHOLE SOIL SAMPLES

Sample Location	Depth (meters)	Radionuclide Concentrations (pCi/g) Th-232 (Ra-228)	Th-228	Ra-226	U-238
B22	Surface	595 ± 8	568 ± 9	59.4 ± 4.1	<51.9
	0.5	7570 ± 50	7840 ± 40	1760 ± 20	180 ± 1
B23	Surface	106 ± 4	118 ± 3	48.2 ± 2.0	<18.7
	0.5	69.6 ± 3.1	75.5 ± 2.2	38.9 ± 1.4	<15.2
	1.0	169 ± 5	189 ± 4	115 ± 3	<24.4
B24	Surface	643 ± 9	589 ± 6	253 ± 5	<49.7
	0.5	430 ± 4	458 ± 4	200 ± 3	18.9 ± 0.7
	1.0	293 ± 4	436 ± 4	79.8 ± 2.1	45.7 ± 0.8
B25	Surface	47.2 ± 1.6	41.6 ± 1.3	8.16 ± 0.73	<8.08
	0.5	31.8 ± 1.5	27.8 ± 1.0	5.99 ± 0.63	<6.56
	1.0	2.95 ± 0.42	3.04 ± 0.32	1.11 ± 0.22	<2.89
	2.0	1.32 ± 0.33	1.38 ± 0.26	0.89 ± 0.20	<3.13
B26	Surface	14.6 ± 0.8	15.0 ± 0.7	7.27 ± 0.53	0.74 ± 0.53
	0.5	18.2 ± 1.0	17.1 ± 0.8	9.74 ± 0.61	<5.84
	1.0	8200 ± 500	7660 ± 500	101 ± 146	106 ± 2
B27	Surface	34.2 ± 1.8	31.9 ± 1.7	3.49 ± 0.80	<9.73
	0.6	3190 ± 20	3160 ± 20	555 ± 14	44.4 ± 1.1
B28	Surface	21.4 ± 1.2	21.7 ± 1.0	4.13 ± 0.56	<6.52
	0.5	9.24 ± 0.72	10.3 ± 0.6	6.51 ± 0.45	2.68 ± 0.48
	1.0	0.91 ± 0.22	0.96 ± 0.19	0.59 ± 0.14	<2.24
	1.5	0.85 ± 0.25	0.96 ± 0.25	0.61 ± 0.18	<2.27
	3.2	4.34 ± 0.56	4.14 ± 0.50	1.23 ± 0.36	<4.18
B29	Surface	184 ± 3	150 ± 3	20.5 ± 1.3	<14.9
	0.5	390 ± 5	347 ± 4	41.6 ± 2.0	46.2 ± 0.8
	1.0	1150 ± 10	808 ± 7	84.5 ± 4.6	79.8 ± 1.0
	3.9	14800 ± 700	15700 ± 600	1450 ± 300	110 ± 1
B30	Surface	46.9 ± 1.5	44.4 ± 1.3	5.33 ± 0.67	<7.02
	1.0	3080 ± 30	2380 ± 20	343 ± 12	53.1 ± 1.0
B31	Surface	26.8 ± 1.1	30.0 ± 1.0	3.43 ± 0.53	<5.88
	0.5	10.7 ± 0.9	13.5 ± 0.6	1.67 ± 0.32	<4.33
	1.0	4.82 ± 0.49	5.95 ± 0.53	0.90 ± 0.28	<3.42
	4.8	35.2 ± 1.4	35.0 ± 1.2	3.76 ± 0.49	<6.67

TABLE 3, cont.

RADIONUCLIDE CONCENTRATIONS IN ON-SITE
BOREHOLE SOIL SAMPLES

Sample Location	Depth (meters)	Radionuclide Concentrations (pCi/g)			
		Th-232 (Ra-228)	Th-228	Ra-226	U-238
B32	Surface	23.1 ± 1.0	26.4 ± 0.9	3.89 ± 0.48	<5.83
	0.5	309 ± 3	254 ± 3	23.9 ± 1.5	26.3 ± 0.7
B33	Surface	47.6 ± 1.6	49.3 ± 1.4	8.42 ± 0.76	<9.02
	0.5	26.7 ± 1.1	24.3 ± 0.9	3.02 ± 0.51	<5.83
	5.4	3.91 ± 0.45	3.60 ± 0.37	1.19 ± 0.27	<3.32
B34	Surface	171 ± 3	178 ± 3	26.5 ± 1.6	<17.9
	0.3	55.1 ± 2.0	57.1 ± 1.5	7.47 ± 0.79	<9.19
	0.5	62.0 ± 1.8	67.3 ± 1.6	11.2 ± 0.8	<9.57
B35	Surface	1.58 ± 0.34	1.48 ± 0.30	0.89 ± 0.22	<3.33
	0.5	2.02 ± 0.38	1.77 ± 0.31	0.81 ± 0.21	<3.32
	1.0	2.01 ± 0.41	2.13 ± 0.29	0.83 ± 0.22	<2.64
	2.0	1.04 ± 0.39	1.21 ± 0.23	0.70 ± 0.17	<2.86
	3.0	1.50 ± 0.30	1.30 ± 0.24	0.81 ± 0.18	<2.59
	6.3	1.27 ± 0.36	1.20 ± 0.28	0.96 ± 0.22	<3.55
B36	Surface	28.0 ± 1.5	29.5 ± 1.1	3.35 ± 0.53	<6.43
	0.5	1.04 ± 0.35	1.21 ± 0.31	0.70 ± 0.22	<2.79
	1.0	1.10 ± 0.29	1.15 ± 0.25	0.62 ± 0.17	<2.78
	2.0	1.35 ± 0.28	1.26 ± 0.24	0.60 ± 0.16	<3.10
	2.5	1.51 ± 0.31	1.21 ± 0.25	0.74 ± 0.18	<2.76
B37	Surface	114 ± 1	112 ± 2	17.3 ± 0.7	18.7 ± 0.6
	0.5	60.4 ± 1.3	61.6 ± 1.1	28.5 ± 0.7	15.9 ± 0.7
B38	Surface	1.98 ± 0.35	1.85 ± 0.34	1.14 ± 0.19	<2.60
	2.0	1.35 ± 0.29	1.41 ± 0.24	0.84 ± 0.19	<0.10
B39	Surface	2.05 ± 0.32	1.91 ± 0.27	0.81 ± 0.18	<2.76
	2.0	2.50 ± 0.38	2.22 ± 0.30	0.92 ± 0.21	<2.90
B40	Surface	2.75 ± 0.42	2.53 ± 0.32	0.79 ± 0.23	<2.60
	0.5	0.88 ± 0.36	1.01 ± 0.29	0.61 ± 0.20	<3.66
	1.8	0.40 ± 0.35	0.55 ± 0.24	0.53 ± 0.15	<2.57
B41	Surface	2.23 ± 0.40	2.24 ± 0.12	0.59 ± 0.20	<3.45
	0.5	1.03 ± 0.35	1.18 ± 0.25	0.61 ± 0.17	<3.09
	1.8	0.67 ± 0.22	0.71 ± 0.23	0.52 ± 0.18	<2.85

TABLE 3, cont.

RADIONUCLIDE CONCENTRATIONS IN ON-SITE
BOREHOLE SOIL SAMPLES

Sample Location	Depth (meters)	Radionuclide Concentrations (pCi/g)			
		Th-232 (Ra-228)	Th-228	Ra-226	U-238
B42	Surface	2.34 ± 0.42	4.22 ± 0.37	0.66 ± 0.20	<3.07
	0.5	2.29 ± 0.35	3.91 ± 0.36	0.78 ± 0.20	<3.19
	1.0	0.66 ± 0.23	2.51 ± 0.30	0.58 ± 0.14	<2.93
	1.5	0.76 ± 0.25	2.37 ± 0.27	0.40 ± 0.14	<2.09
	3.3	2.26 ± 0.35	5.66 ± 0.40	0.60 ± 0.22	<2.63
B43	Surface	12.9 ± 0.8	17.5 ± 0.8	1.64 ± 0.36	<5.23
	0.5	0.82 ± 0.25	3.22 ± 0.32	0.58 ± 0.18	<2.42
	1.0	1.07 ± 0.30	2.55 ± 0.29	0.58 ± 0.20	<2.60
	3.6	7.04 ± 0.58	8.43 ± 0.55	0.79 ± 0.27	1.38 ± 0.47

[a] Refer to Figure 10.
[b] Error is 2σ based on counting statistics only.
[c] Underlined sample locations are those identified during the walkover survey to have elevated exposure rates.

TABLE 4

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES

Sample Location[a]	Description	Radionuclide Concentrations (pCi/g)			
		Th-232 (Ra-228)	Th-228	Ra-226	U-238
D1	Drainage Stream	5.28 ± 0.72[b]	5.04 ± 0.56	1.70 ± 0.35	<4.46
D2	Drainage Stream	2.29 ± 0.55	1.77 ± 0.43	0.51 ± 0.31	<4.05
D3	Drainage Stream	4.72 ± 0.64	2.75 ± 0.43	0.76 ± 0.39	<3.84
D4	Drainage Stream	2.03 ± 0.32	1.73 ± 0.31	0.63 ± 0.20	<2.61
D5	Drainage Tile	5.12 ± 0.46	4.70 ± 0.39	1.31 ± 0.24	<3.22
D6	Drainage Tile	9.17 ± 0.78	9.78 ± 0.59	1.77 ± 0.32	<4.14
D7	Drainage Tile	18.0 ± 1.0	19.1 ± 0.9	3.04 ± 0.47	<6.34
D8	Storm Sewer	16.8 ± 1.0	17.5 ± 0.8	3.65 ± 0.48	6.03 ± 0.51
D9	Storm Sewer	23.4 ± 1.0	25.2 ± 0.9	3.89 ± 0.47	13.6 ± 0.6
D10	Storm Sewer	43.2 ± 1.5	38.7 ± 1.2	4.12 ± 0.61	19.9 ± 0.7
D11	Storm Sewer	24.7 ± 1.3	24.4 ± 1.0	3.67 ± 0.51	<6.36
D12	Storm Sewer	383 ± 4	327 ± 3	30.2 ± 1.8	24.5 ± 0.8
D13	Storm Sewer	78.2 ± 1.9	70.0 ± 1.6	5.37 ± 0.77	12.7 ± 0.6
D14	Storm Sewer	951 ± 6	866 ± 5	101 ± 3	46.9 ± 1.0
D15	Storm Sewer	10.9 ± 0.8	9.57 ± 0.63	1.49 ± 0.33	<4.26

[a] Refer to Figure 12.
[b] Error is 2σ based on counting statistics only.

TABLE 5

RADIONUCLIDE CONCENTRATIONS IN SURFACE WATER SAMPLES

Sample Location[a]	Radionuclide Concentrations (pCi/ℓ or x 10^{-9} μC/ml)			
	Gross Alpha	Gross Beta	Ra-228	Ra-226
W1	7.21 ± 5.69[b]	4.83 ± 7.38	<0.18	0.03 ± 0.03
W2	3.29 ± 4.97	<4.95	c	<0.03
W3	<3.19	<5.00	<0.18	0.11 ± 0.03

[a] Refer to Figure 12.
[b] Error is 2σ based on counting statistics only.
[c] Analysis not performed.

TABLE 6

RADIONUCLIDE CONCENTRATIONS IN STORM SEWER WATER SAMPLES

Sample Location[a]	Radionuclide Concentrations (pCi/ℓ or x 10^{-9} μCi/ml)			
	Gross Alpha	Gross Beta	Ra-228	Ra-226
D10	12.8 ± 5.4[b]	36.1 ± 6.2	1.68 ± 0.20	0.10 ± 0.04
D11	28.6 ± 29.8	60.8 ± 40.3	6.59 ± 0.57	0.19 ± 0.04
D12	17.9 ± 15.7	47.8 ± 18.2	14.2 ± 0.4	0.86 ± 0.08
D13	5.33 ± 7.45	13.4 ± 8.5	8.55 ± 0.42	0.40 ± 0.06
D15	17.5 ± 5.1	26.0 ± 5.3	10.0 ± 0.6	0.15 ± 0.04

[a] Refer to Figure 12.
[b] Error is 2σ based on counting statistics only.

TABLE 7

RADIONUCLIDE CONCENTRATIONS IN ON-SITE VEGETATION SAMPLES

Sample Location[a]	Radionuclide Concentrations (pCi/g)			
	Ra-228	Th-228	Ra-226	U-238
V1	1.00 ± 0.22[b]	0.26 ± 0.17	0.35 ± 0.12	<2.63
V2	1.04 ± 0.15	0.32 ± 0.09	0.07 ± 0.06	<1.22
V3	2.19 ± 0.25	0.48 ± 0.15	0.11 ± 0.10	<2.07
V4	2.15 ± 0.26	0.53 ± 0.14	0.40 ± 0.12	<2.04
V5	3.41 ± 0.36	0.59 ± 0.23	0.30 ± 0.16	<2.51

[a] Refer to Figure 12.
[b] Error is 2σ based on counting statistics only.

TABLE 8

RADIONUCLIDE CONCENTRATIONS IN
SURFACE SOIL SAMPLES FROM ADJACENT PROPERTIES

Sample Location[a]	Radionuclide Concentrations (pCi/g)			
	Th-232 (Ra-228)	Th-228	Ra-226	U-238
S68	1.16 ± 0.31[b]	0.92 ± 0.23	0.69 ± 0.23	1.45 ± 0.52
S69	0.60 ± 0.20	0.64 ± 0.16	0.45 ± 0.17	<1.95
S70	0.78 ± 0.30	0.71 ± 0.22	0.40 ± 0.18	<3.06
S71	0.97 ± 0.27	0.88 ± 0.23	0.49 ± 0.15	<1.93
S72	3.59 ± 0.45	3.62 ± 0.39	0.74 ± 0.25	<3.46
S73	1.22 ± 0.35	1.27 ± 0.29	0.85 ± 0.2	<3.60
S74[c]	227 ± 3	375 ± 4	36.8 ± 1.7	21.2 ± 0.7
S75	75.4 ± 2.2	60.4 ± 1.7	4.85 ± 0.81	19.8 ± 0.7
S76	3.90 ± 0.67	4.17 ± 0.61	1.18 ± 0.38	<4.97
S77	1580 ± 20	1140 ± 10	83.4 ± 6.2	<79.3
S78	319 ± 5	328 ± 6	67.9 ± 2.9	45.4 ± 0.8
S79	8.81 ± 0.80	8.94 ± 0.60	1.63 ± 0.38	<4.70
S80	2.41 ± 0.53	2.41 ± 0.46	1.19 ± 0.36	<5.18
S81	0.97 ± 0.32	1.35 ± 0.25	0.73 ± 0.19	<3.24

[a] Refer to Figure 9.
[b] Error is 2σ based on counting statistics only.
[c] Underlined sample locations are those identified during the walkover survey to have elevated exposure rates.

TABLE 9

RADIONUCLIDE CONCENTRATIONS IN BOREHOLE SOIL SAMPLES FROM ADJACENT PROPERTIES

Sample Location[a]	Depth (meter)	Radionuclide Concentrations (pCi/g) Th-232 (Ra-228)	Th-228	Ra-226	U-238
B44[c]	Surface	2400 ± 20[b]	1360 ± 10	315 ± 9	2.11 ± 0.46
	0.5	2.38 ± 0.39	2.45 ± 0.37	1.06 ± 0.24	<3.23
	1.0	1.05 ± 0.32	1.03 ± 0.24	0.27 ± 0.21	<3.66
B45	Surface	4.59 ± 0.54	4.71 ± 0.49	1.21 ± 0.27	<3.86
	0.5	1.70 ± 0.34	1.61 ± 0.28	0.89 ± 0.21	<2.80
	0.75	1.28 ± 0.29	1.45 ± 0.28	0.85 ± 0.20	<3.36

[a] Refer to Figure 9.
[b] Error is 2σ based on counting statistics only.
[c] Underlined sample locations are those identified during the walkover survey to elevated exposure rates.

TABLE 10

RADIONUCLIDE CONCENTRATIONS IN BOREHOLE SOIL SAMPLES FROM THE ERIE LACKAWANNA RAILROAD PROPERTY

Sample Location[a]	Depth (meters)	Radionuclide Concentrations (pCi/g)			
		Th-232 (Ra-228)	Th-228	Ra-226	U-238
B46[b]	Surface	640 ± 5[c]	639 ± 4	59.4 ± 2.6	45.4 ± 0.8
	0.5	61.6 ± 2.2	67.3 ± 2.0	7.95 ± 0.93	<11.1
	1.0	20.1 ± 1.2	21.7 ± 0.9	2.94 ± 0.46	<5.59
B47	Surface	412 ± 4	401 ± 5	53.0 ± 2.2	49.2 ± 0.9
	0.5	31.1 ± 1.8	31.0 ± 1.2	4.63 ± 0.66	5.55 ± 0.52
B48	Surface	0.85 ± 0.26	0.89 ± 0.23	0.46 ± 0.16	<2.71
	0.5	25.4 ± 1.3	25.0 ± 1.1	4.00 ± 0.56	<7.26
	0.75	12.3 ± 0.9	12.3 ± 0.8	2.75 ± 0.44	<5.06
B49	Surface	1.39 ± 0.3	1.36 ± 0.28	0.59 ± 0.19	<3.09
	0.5	21.3 ± 1.2	21.6 ± 1.0	3.83 ± 0.53	<6.56
	0.75	5.81 ± 0.8	6.97 ± 0.57	2.05 ± 0.37	<4.57
B50	Surface	1.36 ± 0.37	1.09 ± 0.29	0.58 ± 0.22	<2.68
	0.5	4.40 ± 0.54	5.10 ± 0.47	1.48 ± 0.28	<3.66
	0.75	4.53 ± 0.54	5.30 ± 0.48	1.64 ± 0.3	<3.72
B51	Surface	195 ± 4	208 ± 4	28.7 ± 2.00	29.0 ± 0.90
	0.5	3.60 ± 0.45	4.35 ± 0.41	0.91 ± 0.23	<3.48
	1.0	2.80 ± 0.38	2.81 ± 0.36	0.95 ± 0.20	<3.21
B52	Surface	0.76 ± 0.30	0.94 ± 0.24	0.67 ± 0.18	<2.53
	0.5	0.96 ± 0.36	0.90 ± 0.23	0.74 ± 0.21	<2.47
	1.0	0.80 ± 0.27	1.03 ± 0.24	0.76 ± 0.17	<3.59
B53	Surface	0.89 ± 0.26	0.76 ± 0.24	0.49 ± 0.16	<2.53
	0.5	0.94 ± 0.26	1.22 ± 0.26	0.67 ± 0.26	<2.65
	1.0	0.91 ± 0.32	0.92 ± 0.21	0.69 ± 0.16	<2.77
B54	Surface	0.73 ± 0.30	0.83 ± 0.24	0.61 ± 0.21	<2.81
	0.5	0.92 ± 0.36	1.06 ± 0.28	0.65 ± 0.18	<2.83
	1.0	3.51 ± 0.42	4.10 ± 0.37	1.27 ± 0.23	<2.88

[a] Refer to Figure 11.
[b] Error is 2σ based on counting statistics only.
[c] Underlined sample locations are those identified during the walkover survey to have elevated exposure rates.

TABLE 11

RADIONUCLIDE CONCENTRATIONS IN VEGETATION SAMPLES FROM VICINITY OF THE ERIE LACKAWANNA RAILROAD IN POMPTON PLAINS, NEW JERSEY

Sample Location[a]	Radionuclide Concentrations (pCi/g)			
	Ra-228	Th-228	Ra-226	U-238
V6[c]	0.28 ± 0.10[b]	0.18 ± 0.08	0.16 ± 0.04	<1.38
V7	0.12 ± 0.07	0.04 ± 0.06	0.05 ± 0.03	<0.88
V8	<0.06	0.24 ± 0.12	<0.03	<1.67

[a] Refer to Figure 11.
[b] Error is 2σ based on counting statistics only.
[c] Underlined sample locations are those identified during the walkover survey to have elevated exposure rates.

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APPENDIX A

GLOSSARY OF TERMS

Glossary

Activation:	The process of making a material radioactive by bombardment with neutrons, protons, or other nuclear particles.
Activity:	Radioactivity, the spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nuclei of an unstable nuclide. As a result of this emission, the radioactive material is converted (or decays) into a different nuclide (daughter), which may or may not be radioactive. Ultimately, as a result of one or more stages of radioactive decay, a stable (nonradioactive) nuclide is formed.
Aerial survey:	A search for sources of radiation by means of sensitive instruments mounted in a helicopter or airplane. Generally, the instrumentation records the intensity, location, and spectral analysis of the radiation.
Alpha particle:	A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together, and hence is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation (alpha, beta, gamma) emitted by radioactive material, and can be stopped by a sheet of paper.
Background radiation:	The radiation in man's natural environment, including cosmic rays and radiation from the naturally radioactive elements. It is also called natural radiation. The term may also mean radiation that is unrelated to a specific experiment. Levels vary, depending on location.
Baseline concentration:	The concentration of a given substance typically encountered in the area under consideration, i.e. the normal or naturally occurring level.
Beta particle:	An elementary particle emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron.
Contamination:	Undesired radioactive materials that have been deposited on surfaces, are internally ingrained into structures or equipment, or that have been mixed with another material.

Curie: A special unit of activity. One curie equals 3.7×10^{10} nuclear disintegrations per second. Several fractions of the curie are in common usage:

-- Millicurie - one thousandth of a curie. Abbreviated as mCi.

-- Microcurie - one millionth of a curie. Abbreviated as μCi.

-- Nanocurie - one billionth of a curie. Abbreviated as nCi.

-- Picocurie - one trillionth of a curie. Abbreviated as pCi.

Daughter: The product of radioactive decay of a nuclide. (also see Parent).

Decay, radioactive: The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The process results in a decrease, with time, of the number of original radioactive nuclides in a sample. It involves the emission from the nucleus of alpha particles, beta particles, or gamma rays; or the nuclear capture or ejection of orbital electrons; or fission. Also called radioactive disintegration.

Decontamination: Those activities employed to reduce the levels of contamination.

Dose: A measure of the quantity of radiation absorbed in a unit mass of a medium. The unit of dose is the rad.

Dose rate: The radiation dose delivered per unit time and measured, for example, in rads per hours.

Exposure: A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. The special unit of exposure is the roentgen.

Exposure rate: The radiation exposure per unit time. Measured, for example, in roentgens per hour.

Gamma radiation: High-energy, short-wave length electromagnetic radiation of nuclear origin (radioactive decay). Gamma rays are the most penetrating of the three common types of radiation.

Half-life: The time in which half the atoms of a particular radioactive sustance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years.

Microrad (μrad): A submultiple of the rad, equal to one-millionth of a rad. (see rad).

Microroentgen (μR): A submultiple of the roentgen, equal to one-millionth of a roentgen. (see roentgen).

Millirem (mrem): A submultiple of the rem, equal to one-thousandth of a rem. (see rem).

Natural uranium: Uranium as found in nature, containing 0.7 percent of uranium-235, 99.3 percent of uranium-238. It is also called normal uranium.

Natural thorium: Thorium as found in nature. Natural thorium contains equal activity level of thorium-232 and thorium-228.

Parent: A radionuclide which disintegrates or decays to produce another nuclide which is also radioactive. This second radionuclide is known as the daughter product.

Picocurie (pCi): One-trillionth (10^{-12}) of a curie.

Rad: The unit of absorbed dose. The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. One rad equals 0.01 joules/kilogram of absorbing material.

Radiation: Energetic nuclear particles including neutrons, alpha particles, beta particles, x-rays, and gamma rays (nuclear physics). Also includes electromagnetic waves (radiation) of any origin.

Radioactivity: The property of certain nuclides of spontaneously emitting particles, or gamma radiation. Often shortened to "activity."

Radionuclide: A general term applicable to any radioactive form of the elements, a radioactive nuclide.

Radium (Ra): A radioactive metallic element with atomic number 88. As found in nature, the most common isotope has an atomic weight of 226. It occurs in minute quantities associated with uranium in pitchblende, carnotite, and other minerals; the uranium decays to radium in a series of alpha and beta emissions. By virtue of being an alpha- and gamma-emitter, radium is used as a source of illuminescence and as a radiation source in medicine and radiography. The isotope of radium with an atomic weight of 228 is found in the thorium decay series.

Radon (Rn): The heaviest element of the noble gases, produced as a gaseous emanation from the radioactive decay of radium. Its atomic number is 86. All isotopes are radioactive. Rn-222 is an isotope with a half-life of 3.82 days.

Rare earths: A group of 15 chemically similar metallic elements, including elements 57 through 71 on the Periodic Table of the Elements, also known as the Lanthanide Series.

Rem: The unit of ionizing radiation that produces the same biological damage to man as a unit of absorbed dose (1 roentgen) of high voltage x-rays.

Roentgen (R): A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying one electrostatic unit of electrical charge (either positive or negative) in one cubic centimeter of dry air under standard conditions.

Secular Equilibrium: The state which prevails when the rate of formation of a radioactive material equals the material's rate of decay. Although, by theory, this condition is never completely achieved, it is essentially established in the thorium decay series as it occurs in nature.

Survey: An evaluation of the radiation hazards incidental to the production, use, or existence of radioactive materials or other sources of radiation under a specific set of conditions.

Thorium (Th): A naturally occurring radioactive element with atomic number 90 and, as found in nature, an atomic weight of approximately 232.

Thorium series: The series (sequence) of nuclides resulting from the radioactive decay of thorium-232. Many man-made nuclides decay into this sequence. The end product of the sequence in nature is lead-208.

Uranium (U): A radioactive element with the atomic number 92 and, as found in natural ores, an average atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7 percent of natual uranium) and uranium-238 (99.3 percent of natural uranium). Natural uranium also includes a minute amount of uranium-234.

Uranium series: The series (sequence) of nuclides resulting from the radioactive decay of uranium-238. The end product of the series is lead-206.

EXPLANATION OF SYMBOLS AND UNITS

Symbols	Unit	English Equivalents
cm	centimeter (x 10^{-2} meters)	0.394 inches
g	gram	0.032 ounces
h	hour	-----
kg	kilogram (x 10^{3} grams)	2.2 pounds
km	kilometer (x 10^{3} meters)	0.622 miles
l	liter	0.264 gallons
m	meter	3.28 feet
ml	milliliter (x 10^{-3} liters)	0.061 cubic in.
mrem	millirem (x 10^{-3} rem)	-----
pCi	picocurie (x 10^{-12} curies)	-----
Ra	Radium	-----
U	Uranium	-----
Th	Thorium	-----
μCi	microcurie (x 10^{-6} curies)	-----
μrad	microrad (x 10^{-6} rads)	-----
μR	microroentgen (x 10^{-6} roentgens)	-----

APPENDIX B

THORIUM AND URANIUM DECAY SERIES

Appendix B

Thorium Decay Series

Parent	Half-Life	Major Decay Products	Daughter
Thorium-232	14 billion years	alpha	Radium-228
Radium-228	5.8 years	beta	Actinium-228
Actinium-228	6.13 hours	beta, gamma	Thorium-228
Thorium-228	1.91 years	alpha	Radium-224
Radium-224	3.64 days	alpha	Radon-220
Radon-220	55 seconds	alpha	Polonium-216
Polonium-216	0.15 seconds	alpha	Lead-212
Lead-212	10.6 hour	beta, gamma	Bismuth-212
Bismuth-212	60.6 minutes	alpha (1/3)* beta (2/3)*	Thallium-208 Polonium-212
Thallium-208	3.1 minutes	beta, gamma	Lead-208
Polonium-212	0.0000003 seconds	alpha	Lead-208
Lead-208	stable	none	none

* Two decay modes are possible for Bismuth-212.

Uranium Decay Series

Parent	Half-Life	Major Decay Products	Daughter
Uranium-238	4.5 billion years	alpha	Thorium-234
Thorium-234	24 days	beta, gamma	Protactinium-234
Protactinium-234	1.2 minutes	beta, gamma	Uranium-234
Uranium-234	250,000 years	alpha	Thorium-230
Thorium-230	80,000 years	alpha	Radium-226
Radium-226	1,600 years	alpha	Radon-222
Radon-222	3.8 days	alpha	Polonium-218
Polonium-218	3 minutes	alpha	Lead-214
Lead-214	27 minutes	beta, gamma	Bismuth-214
Bismuth-214	20 minutes	beta, gamma	Polonium-214
Polonium-214	2/10,000 second	alpha	Lead-210
Lead-210	22 years	beta	Bismuth-210
Bismuth-210	5 days	beta	Polonium-210
Polonium-210	140 days	alpha	Lead-206
Lead-206	stable	none	none

APPENDIX C

GROUND-PENETRATING RADAR SURVEY
OF THE
W.R. GRACE SITE
WAYNE, NEW JERSEY

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1. INTRODUCTION

A ground penetrating radar (GPR) survey was conducted during the week of July 12, 1982 at the W.R. Grace site, Pompton Plains, New Jersey. The survey was performed under contract to the Oak Ridge Associated Universities (ORAU) in support of their assessment of the radiological conditions at the site. The objectives of the GPR Survey were:

1. to define the exact location of burial trenches, and
2. to identify the locations and depths of subsurface objects.

The results of this survey will allow further radiological site assessment to proceed in an efficient manner. These results are discussed in section 5 of this report.

In addition to radar soundings, bulk soil resistivity measurements were made. These measurements aided in the selection of the optimum GPR system parameters, and were used to estimate system capability, particularly depth of penetration, in the site geology.

2. W.R. GRACE SITE DESCRIPTION

Monazite sands were processed at the site in the period from 1948 to 1967 to extract thorium and rare earths. The resulting waste products were buried in shallow excavations as permitted by regulations (10CFR20.304) governing licenses of the Atomic Energy Commission.

The site, which occupies approximately 2.6 hectares, is located on Black Oak Ridge Road 1.5 miles north of Wayne, New Jersey, in a residential and light commercial district. Three main buildings are located on the west side of the property, which is mostly paved for parking and loading facilities. The burial area on the eastern part is open land covered with weeds and a few small trees, having a gradual downward slope from east to west. A small stream courses north along the eastern boundary and loops west to exit the property at the north west corner. A few isolated piles of debris are the only visible evidence of disposal activity. A tall chain link fence encompasses the site.

A grid system, shown in Figure 1, was established on the site based on 20 meter centers identified by lettered and numbered markers. In the burial area these were wooden stakes driven into the ground. In the paved areas, bench nails were used. The lettered rows, A+10m through G+18m, ran north-south with row A+10m at the western edge. Subsequent rows progressed alphabetically toward the east. Numbered rows, -1 through 7, ran east-west with numbers increasing towards the north. This grid gave comprehensive coverage of the property.

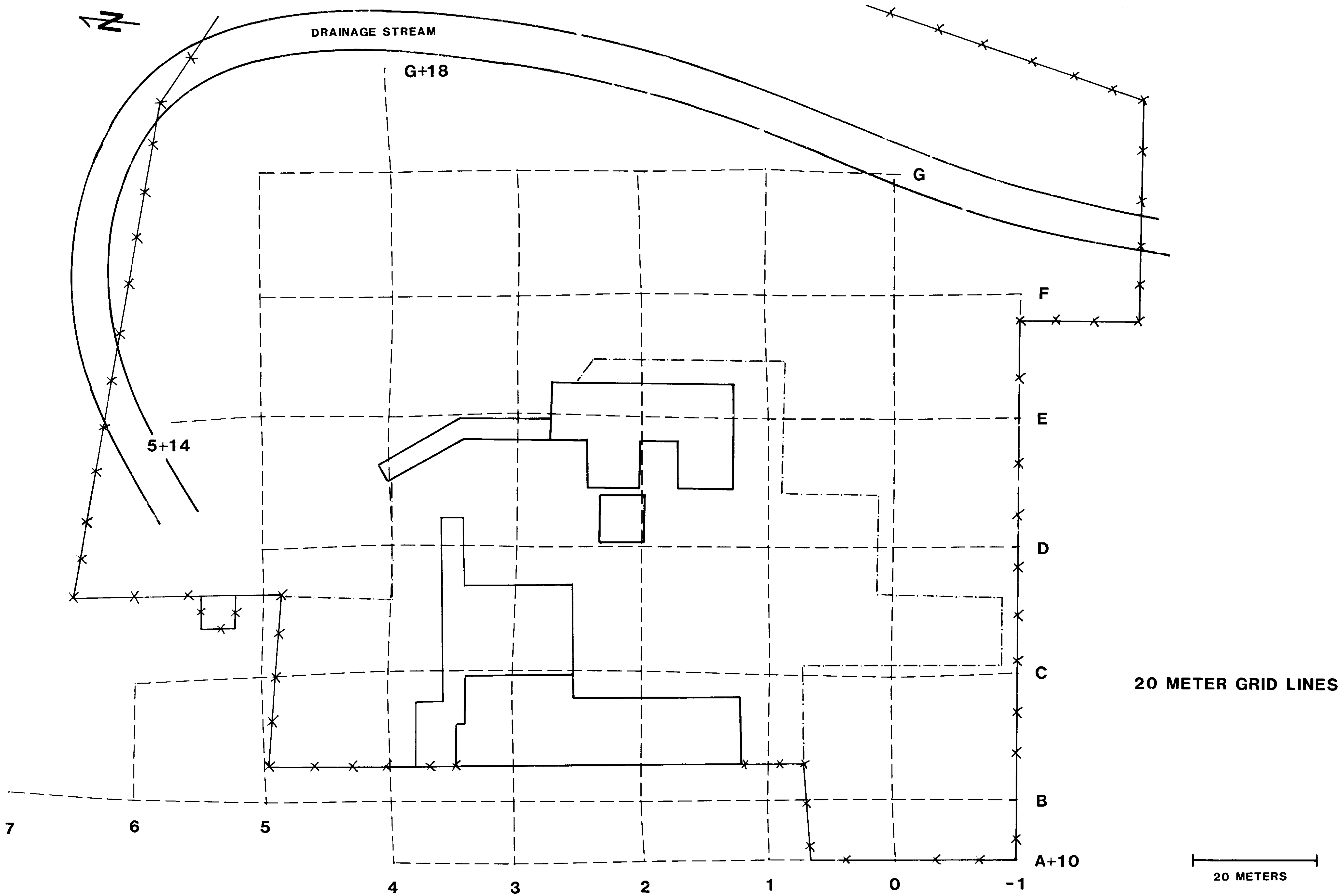


Figure 1: Map showing accessible portion of the W. R. Grace Disposal Site and 20-meter grid system.

3. FIELD MEASUREMENT TECHNIQUES

This section describes the geophysical measurement techniques of ground penetrating radar (GPR) and electrical resistivity (ER) that were used in this survey. Section 3.1 reviews the theory of GPR, while Section 3.2 describes the GPR instrumentation used to make the measurements. Section 3.3 reviews the electrical resistivity techniques and instrumentation.

3.1 Ground Penetrating Radar Theory

Subsurface radar detection systems have been the object of study for over a decade by both military and environmental agencies. In both applications, the objectives are to locate and identify buried or submerged objects, otherwise not detectable, and to spatially determine the structural make-up of the subsurface.

The principle of operation involves the generation of a pulse train of electromagnetic radiation in the frequency range of 10-1000 MHz. In accordance with the laws of classical electromagnetism, the wave propagates, with material dependent attenuation, through a given medium - the earth. When the wavetrain encounters a material or boundary of different electromagnetic properties, the wave is partially reflected. This reflected wave is then detected and the time interval between transmission and detection is recorded.

With knowledge of the velocity of propagation, the time interval can be converted to a range or depth.

As part of the calibration process the velocity of propagation of the electromagnetic wave in the particular medium is determined. For earth materials with a relative effective dielectric constant, ε_{er}, the velocity of propagation, v_m, of the electromagnetic signals, is usually approximated by:

$$v_m = \frac{c}{\varepsilon_{er}^{1/2}} \tag{1}$$

where: $c = 3 \times 10^8$ m/sec, the propagation velocity in free space. However, equation (1) is actually derived from

$$v_m = \frac{\omega}{\beta} \tag{2}$$

where: $\omega = 2\pi f$ = angular frequency

f = frequency in Hertz

β = phase constant, imaginary part of propagation constant.

The phase constant, β, is obtained from γ, the complex propagation constant of the medium which is derived from Maxwell's equations describing the behavior of electromagnetic fields. The propagation constant, γ, is defined as:

$$\gamma = \alpha + j\beta = (-\omega^2 \mu' \varepsilon_e + j\omega\mu'\sigma_e)^{1/2} \tag{3}$$

where: α = attenuation constant

μ' = magnetic permeability of the medium

σ_e = effective conductivity

The probing depth is determined by the frequency of operation and the electromagnetic properties of the soil, principally the conductivity and the dielectric constant. Signal attenuation, A, usually given in terms of dB/meter (Morey, 1974), is approximated by:

$$A = (12.863 \times 10^{8})\ f\ (\varepsilon_{er})^{\frac{1}{2}}\ ((p + 1)^{\frac{1}{2}} - 1)^{\frac{1}{2}} \qquad (4)$$

where: p = loss tangent $= \dfrac{\sigma_e}{2\pi f \varepsilon_o \varepsilon_{er}} = \dfrac{1.8\sigma_e}{f\ \varepsilon_{er}} \times 10^{10}$

ε_o = dielectric constant of free space

$= 8.85 \times 10^{-12}$ farads/meter

Equation (4) is derived from:

$$A = 20 \log e^{\alpha} = 8.686\ \alpha \qquad (5)$$

Nominal GPR systems transmit approximately 100 volts and can readily detect 1 millivolt, giving 100 dB of usuable signal. However, the attenuation increases with increasing frequency. Thus, by changing the radar frequency through the use of different antennas, a range of probing depth of resolution is made available.

In common earth materials there is a trade-off between probing depth and resolution. Quantitatively, the spatial resolution, r, is approximated by one-half the radar wavelength in the medium:

$$r = \lambda/2 = v_m/(2f) = c/(2f\ \varepsilon_{er}^{\frac{1}{2}}) \qquad (6)$$

using equation (1) in the derivation, or

$$r = \lambda/2 = v_m/(2f) = (\omega/\beta)/(^2b) = \pi/\beta \qquad (7)$$

using equation (2)

A summary of the physical properties of common media which affect the propagation and attenuation of electromagnetic signals is shown in Table 1. Careful analysis of the reflected pulse, combined with a knowledge of the electromagnetic properties of the soil, can reveal information such as percentage of water content, density variation, and the location and depth of buried objects.

Table 1: Approximate VHF electromagnetic parameters of typical earth materials.

Material	Approximate Conductivity σ (mho/m)	Approximate Dielectric Constant	Depth of Penetration
Air	0	1	Max (km)
Limestone (dry)	10^{-9}	7	↓
Granite (dry)	10^{-8}	5	
Sand (dry)	10^{-7} to 10^{-3}	4 to 6	
Bedded Salt	10^{-5} to 10^{-4}	3 to 6	
Freshwater Ice	10^{-5} to 10^{-4}	4	
Permafrost	10^{-4} to 10^{-2}	4 to 8	
Sand, Saturated	10^{-4} to 10^{-2}	30	
Freshwater	10^{-4} to 3×10^{-2}	81	
Silt, Saturated	10^{-3} to 10^{-2}	10	
Rich Agricultural Land	10^{-2}	15	
Clay, Saturated	10^{-2} to 1	8 to 12	↓
Seawater	4	81	Min (cm)

Inference as to the composition of the reflecting and intervening material is possible, depending on the intensity and phase of the return signal. For example, metallic objects have different dielectric properties than soils and will, therefore, give rise to strong reflections and a phase shift. Geological interfaces, on the other hand, give relatively weak reflections and no significant phase shift. The complex reflection coefficient, ρ, in the case of reflection involving a two-layer earth is given by:

$$\rho = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \tag{8}$$

where: η_1 = complex impedance of upper layer

η_2 = complex impedance of lower layer

The complex impedance is derived from:

$$\eta = \frac{j\omega\mu'}{\gamma} \tag{9}$$

where γ is given by equation (3). Table 2 compares typical electromagnetic properties at 100 MHz of some of the materials listed in Table 1.

A more quantitative picture of the penetration performance of the GPR is shown in Figure 2. Here, the range or depth (for different electromagnetic frequencies) is plotted directly as a function of attenuation in various media. The plots result from calculations assuming the return signal is from a rough plane reflector with a reflection coefficient equal to 1.0.

Table 2

Typical Electromagnetic Properties of Materials at 100 MHz

Material	A dB/m	V_m cm/ns	η Ohms
Air	0	30	377
Fresh Water	0.18	3.33	42+j0.046
Sea Water	326	1.50	10+j9.33
Sandy Soil, Dry	0.44	16.0	202+j2.6
Loamy Soil, Wet	1.93	7.07	88.8+j2.6
Clayey Soil, Wet	12.5	7.63	93+j16.2
Iron	1.7×10^{7}	3.2×10^{-5}	2.0+j2.0
Basalt	8.2×10^{-3}	15.0	188+j0.04
Sandstone	0.73	13.4	168+j3.0

Where η = Characteristic Impedance of Material

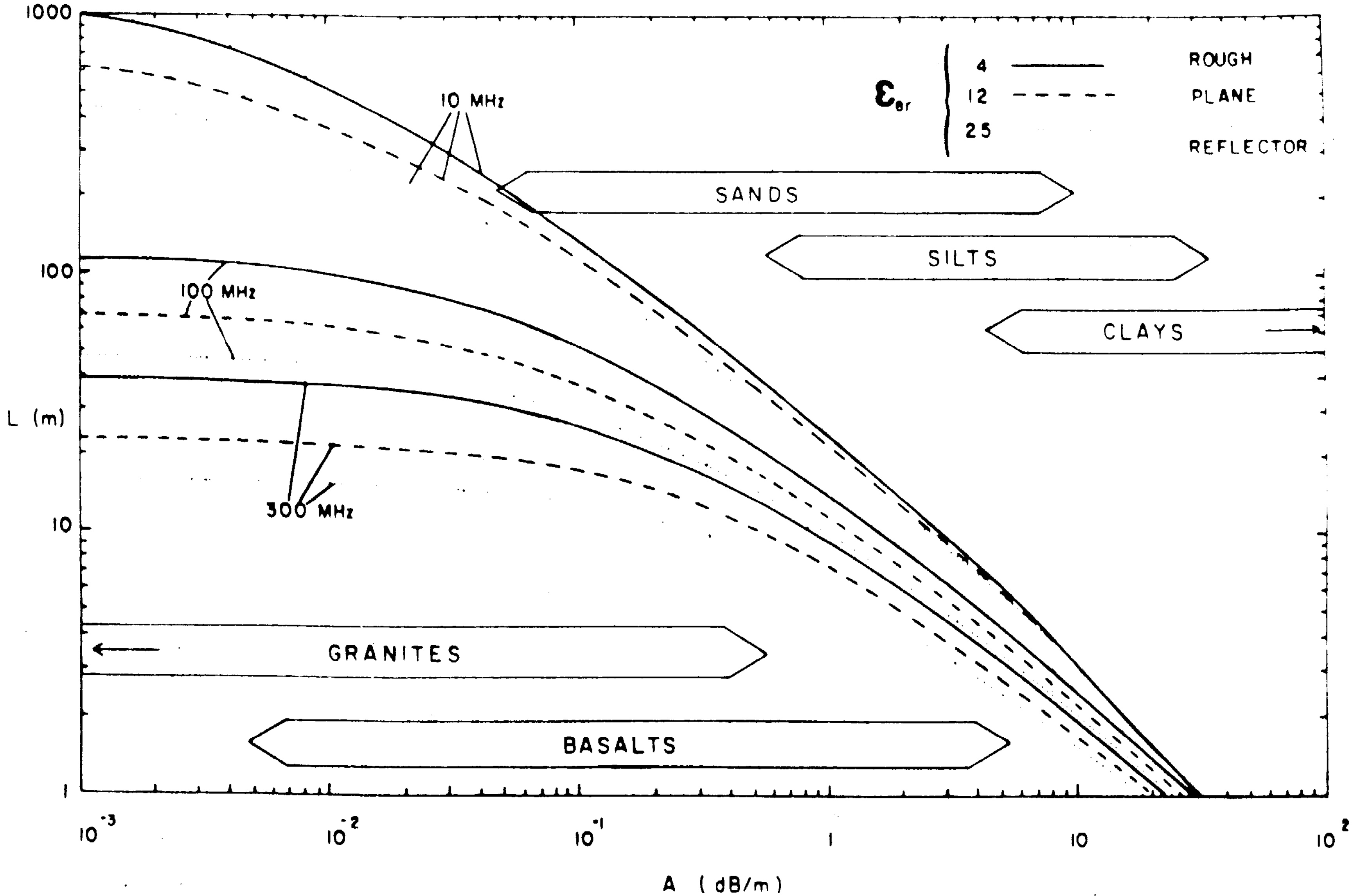


Figure 2: Variation of maximum depth of penetration (L) as a function of attenuation (A) for different frequencies and dielectric constants. Typical ranges of attenuation for different earth materials are also shown (after Horton et al, 1981).

Table 3. Selected Radar Parameters for Calculating Maximum Range

RADAR SYSTEM PARAMETERS

System	Geo-Centers Proprietary Design	Standard GSSI Systems	
Center frequency	10 MHz	80/120 MHz	300 MHz
Parameter			
P_s(Peak) (Watts)	2.5×10^3	50	12
P_{min}(Watts)	2.5×10^{-8}	5×10^{-10}	1.2×10^{-10}
Q	-110 dB	-110 dB	-110 dB
$E_t = E_r$	5%(-13 dB)	5%(-13 dB)	5%(-13 dB)
$G_t = G_r$	1.585(2 dB)	1.585(2 dB)	1.585(2 dB)

3.2 Ground Penetrating Radar Instrumentation

A Geophysical Survey Systems, Inc., (GSSI) System 7 was used to conduct the survey. Figure 3 is a block diagram of a typical GPR system. The equipment consists of a portable, gasoline powered electrical generator, a power supply, a control unit, a graphic recorder, and a tape recorder all mounted in a vehicle. A number of antennas were available for use on this program. Frequencies ranged from 10 MHz (Geo-Centers' proprietary deep penetrating antenna) to 300 MHz. Table 3 summarizes the characteristics of several of the available antennas. Data were recorded on magnetic tape and on a hard-copy graphic recorder; the latter information was compressed because of the high input data rate. After the field survey, the magnetic tape was played at a slower speed to generate full-resolution hard copy for analysis.

3.3 Electrical Resistivity Techniques and Instrumentation

Earth resistivity surveys have been used for many years in exploration for ground water and mineral deposits, and in the study of engineering properties of earth materials. Equipment to measure resistivity consists of a controlled source of electric current, a device for measuring the potential differences generated by the current passing through the earth and a number of electrodes for coupling the current into the earth. The volume of subsurface material influencing the resistivity measurement is controlled by the spacing and geometry of the electrodes. While any array of four or more electrode contracts can be used in studying earth resistivity, relatively few electrode configurations have been accepted as standard arrays in practice. Figure 4 shows the three most common electrode arrays used in the resistivity method. Many

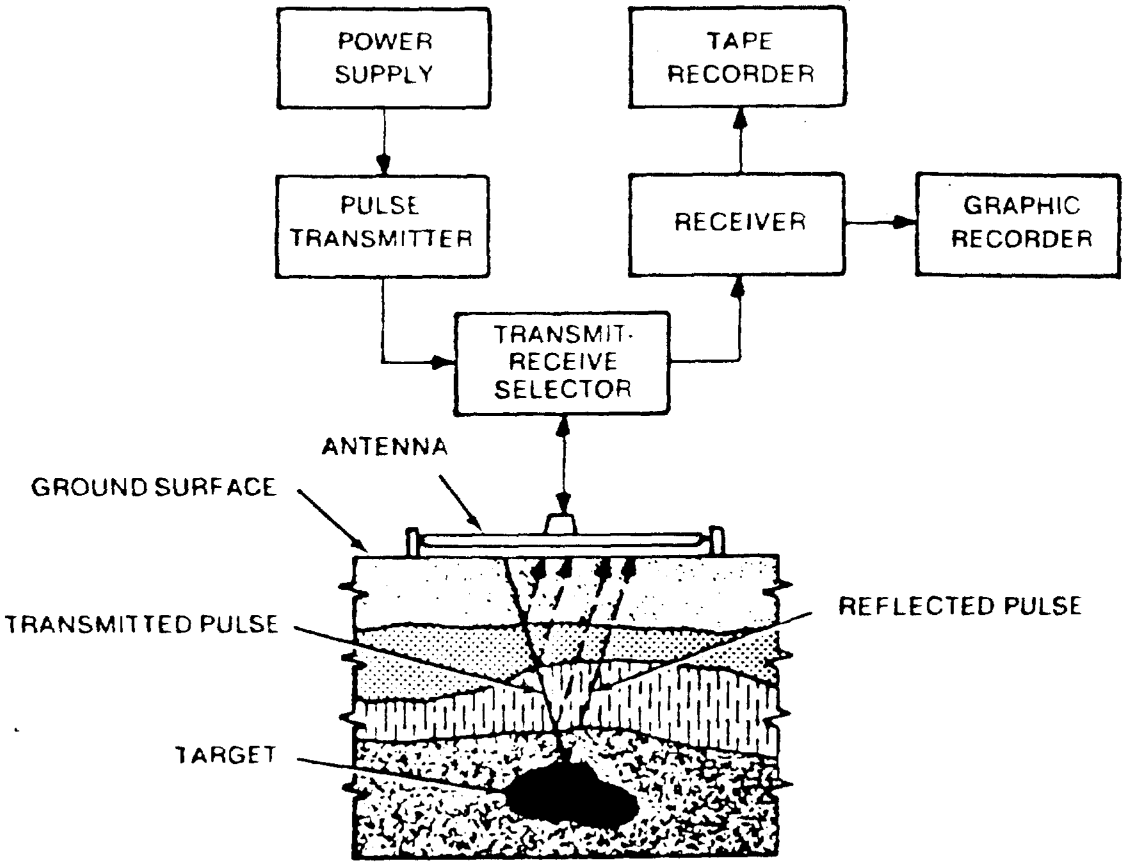
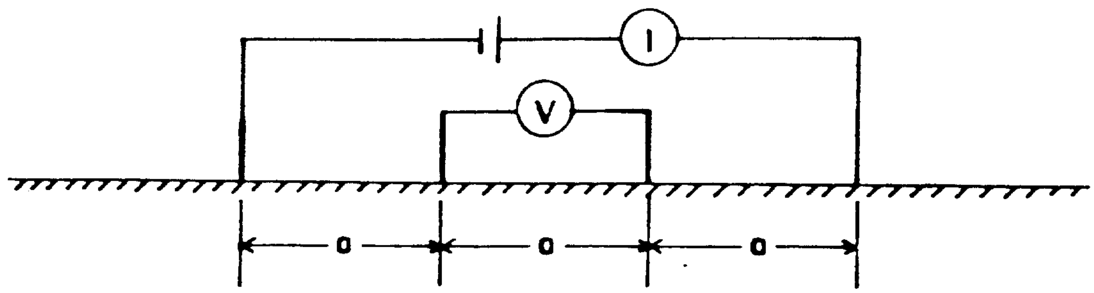
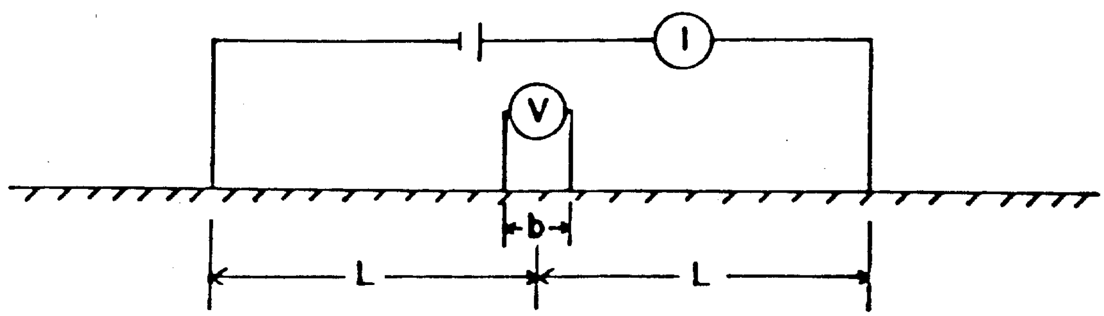


Figure 3 Ground-Penetrating Radar (GPR) System, block diagram.

(a) Wenner Spread



(b) Schlumberger Spread



(c) Double-dipole Spread

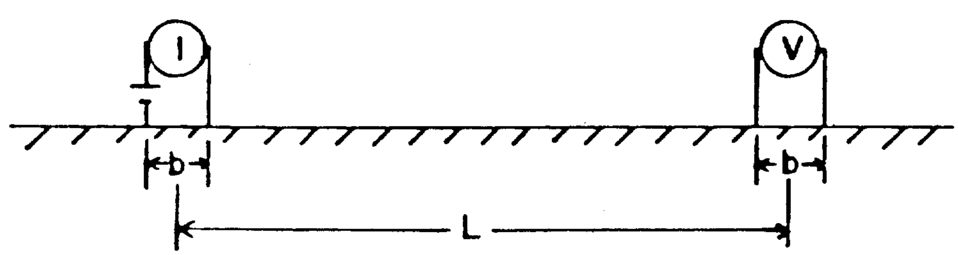


Figure 4: Common electrode configurations for resistivity arrays.

factors are considered in the choice of array configurations for a given problem. Susceptibility to geological noise, ease of array movement, and the nature of the assumed structure are a few of these factors.

For each of the three (3) electrode configurations in Figure 4, the apparent resistivity, ρ_a, can be calculated from:

$$\rho_a = 2\pi \frac{V}{I} a, \text{ Wenner Array} \qquad (10a)$$

Where: V = potential difference
I = induced electric current
a = spacing between electrodes

$$\rho_a = \pi \frac{V}{I} (b) \left[\left(\frac{L}{b}\right)^2 - \tfrac{1}{4} \right], \text{ Schlumberger Array} \qquad (10b)$$

Where: b = distance between potential electrodes
L = half the distance between current electrodes

$$\rho_a = \pi \frac{V}{I} (L) \left[\left(\frac{L}{b}\right)^2 - 1 \right], \text{ Double-dipole array} \qquad (10c)$$

Where: b = distance between current electrodes and between potential electrodes.
L = distance between mid-points of current electrodes and potential electrodes.

As discussed in section 3.1, a knowledge of soil properties allows prediction of radar performance at a specific site. Measurements of bulk soil resistivity can be used to estimate expected penetration depth of the GPR. Figure 5 shows maximum radar range as a function of electrical resistivity (DC conductivity). From a few measurements of resistivity on the site of interest, the expected depth of penetration can be estimated for a range of frequencies. The best antenna for the application can then be selected, providing the optimum trade-off between penetration and resolution.

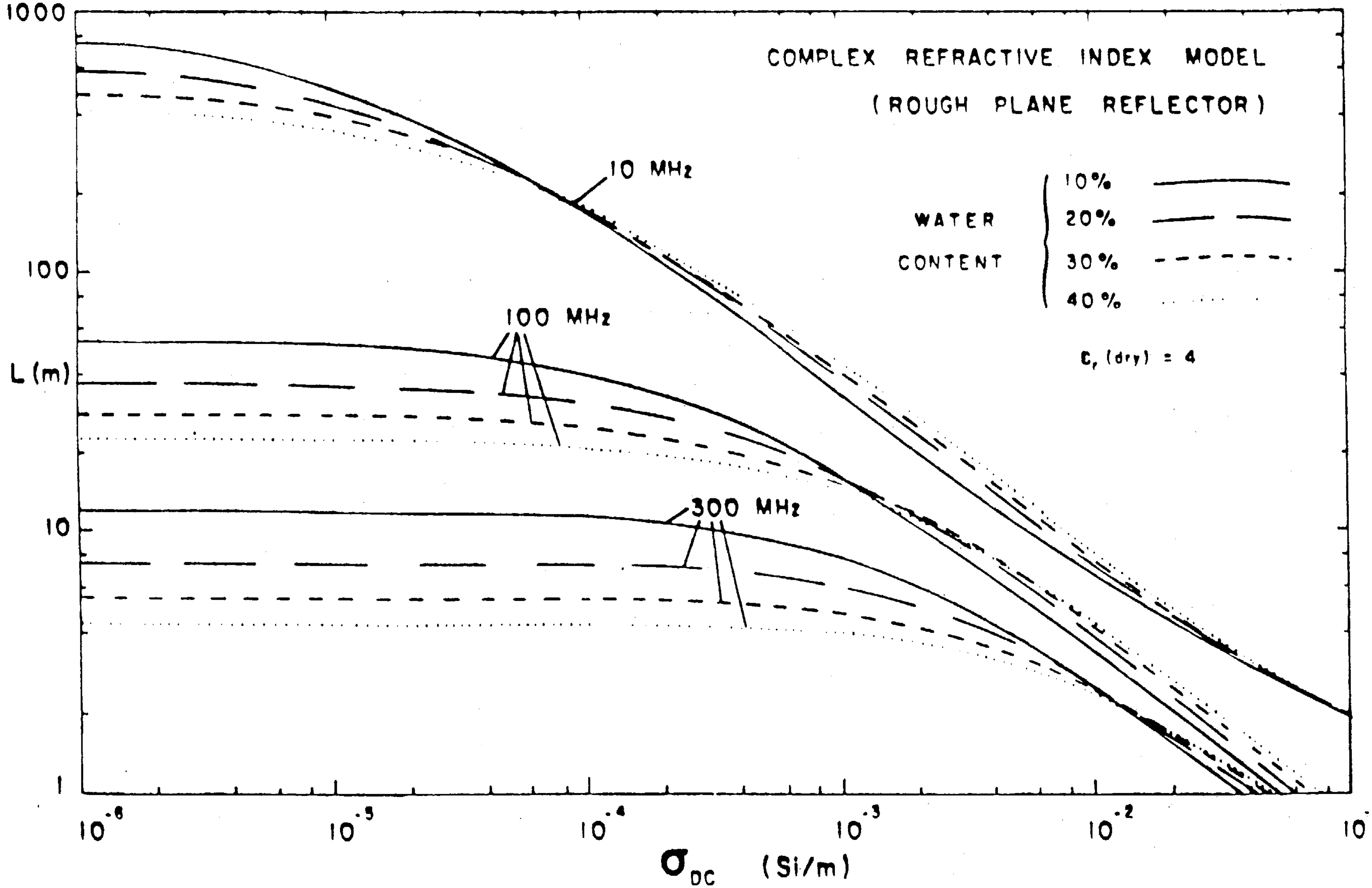


Figure 5: Radar range (L) as a function of DC conductivity (σ_{DC}) at different frequencies. Plots are based on a Complex Refractive Index Soil Model and reflection from a rough plane reflector. (after Horton et al, 1981).

In addition to supporting radar operations, mapping the site with resistivity measurements aids in the interpretation of radar data. Changes in bulk resistivity can indicate the presence of materials foreign to the particular site. For example, a cluster of metallic objects would lower the resistivity values measured for the area surrounding these materials. Correlations between resistivity measurements and GPR measurements are strong indications of disturbed areas.

4. OPERATIONS

The grid system with 20 meter centers was used as the coordinate system for the GPR scan lines and the resistivity measurements. For estimating GPR depth of penetration, bulk resistivity data were collected along the east-west, numbered grid lines using the Wenner spread (Figure 4) with the spacing, a, equal to 10 feet. The measurements ranged from 2 to 72 ohm-meters, or in terms of conductivity, from 0.5 to 1.39 X 10^{-2} Si/meter. The average for the site, taken over 86 readings, was 20.14 ohm-meters (4.97 X 10^{-2} Si/meter). From Figure 5, this resulted in a predicted range of penetration depths for the 80 MHz antenna of 1 to 5 meters (3 to 16 feet).

A depth value was derived from the time interval measurements between the transmit and receive pulses by using Equation 2 to calculate the velocity of propagation of the pulse in the earth medium. The value of the relative dielectric constant, ε_{er}, was estimated to be 25 by comparing the soil at the W.R. Grace site with similar materials. This yielded a velocity of propagation of approximately 5.86 cm/nsec. Using this value in Equation 7 gives a calculated resolution for the 80 MHz antenna of 1.5 meters (4.92 feet).

The antenna was towed along a series of survey lines to cover the site in a thorough manner. The survey lines are shown in Figure 6 superimposed on a diagram of the site. The antenna was towed manually for scans less than 20 meters in

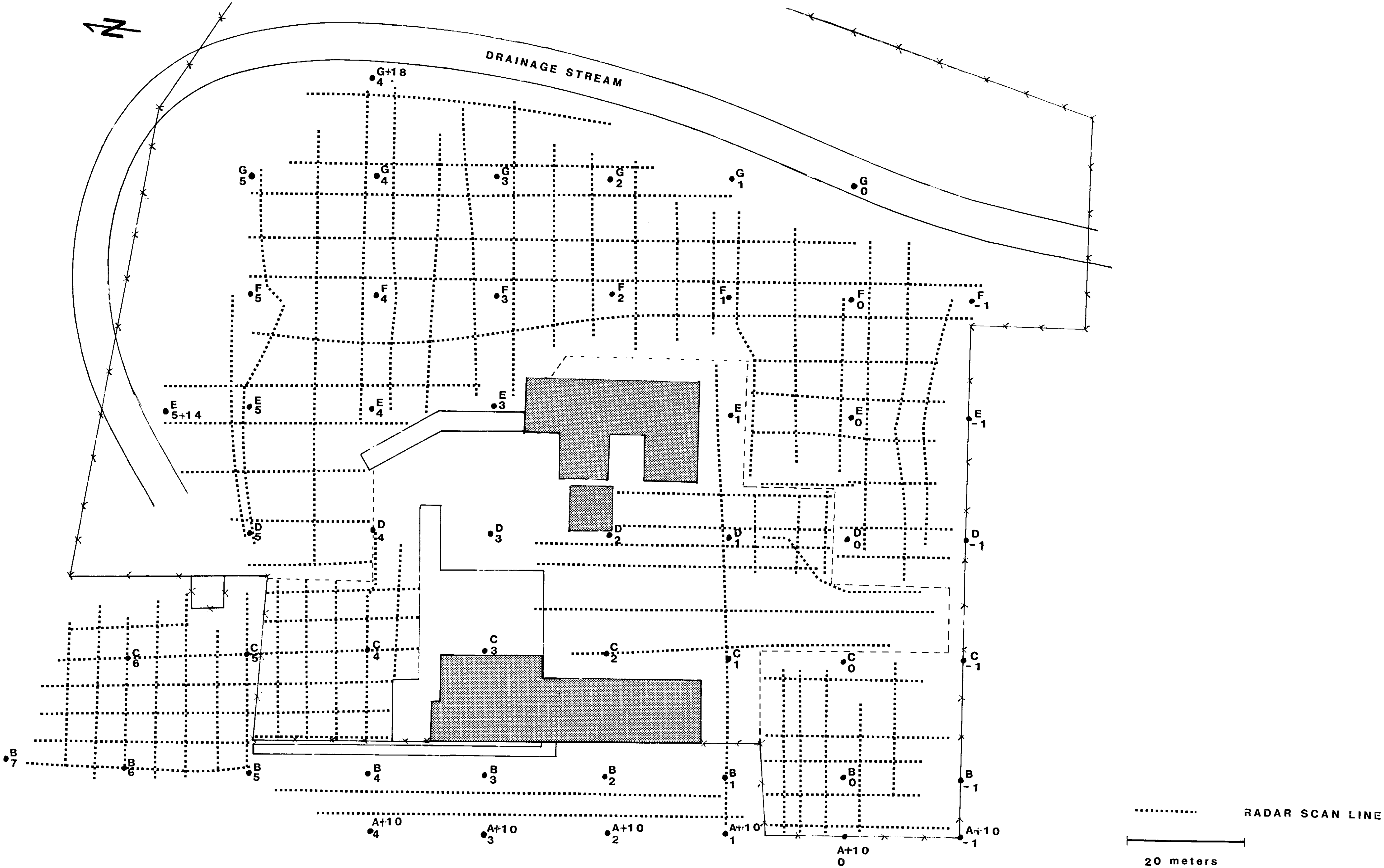


Figure 6: Radar survey lines.

length and for scans in level, paved areas. Otherwise, the antenna was secured to the back of the vehicle carrying the electronic equipment. Scan lines deviated from the straight grid system when it was necessary to avoid obstacles such as trees and piles of debris. Towing speeds were kept as constant as possible, averaging 2 to 3 mph. As the antenna passed each grid marker, the data tape was indexed, thus adding distance markers to the graphic display copy.

5. DISCUSSION OF RESULTS

The 300 MHz and the 80 MHz antenna systems were evaluated and calibration measurements were made to tailor the radar system for the specific conditions at the W.R. Grace site. Data collected with the 300 MHz antenna indicated a depth of penetration of approximately 1 to 8 feet, which precluded its use. The results in this report were derived from data obtained with the 80 MHz antenna.

Typical examples of radar profiles taken at the site are displayed in Figures 7 and 8. Figure 7 shows a scan along the F+3m, line from -1+00m to 5+00m. Figure 8 shows a scan along the 5-2m line from G+2m to D-2m

In Figure 7, several distinct, well defined regions are readily apparent. At the beginning of the scan near -1+2m, a sharply delineated area of strong reflectivity about 3m wide stands out. A gradual transition from a strong reflective zone to a moderate reflective zone occurs near 0-4m. The area from 0+00m to 1+00m is nearly uniform, with numerous small reflections evident at depth. A sharp transition is visible close to 1+00m leading into a region of irregular, individual scatterers. This region ends at 1+9m where an absorptive zone containing a number of diffuse scatters is encountered. The strong vertical signature at 2+3m is probably due to a near surface metallic object. Beginning with 2+5m the shallow return signal becomes increasingly disturbed,

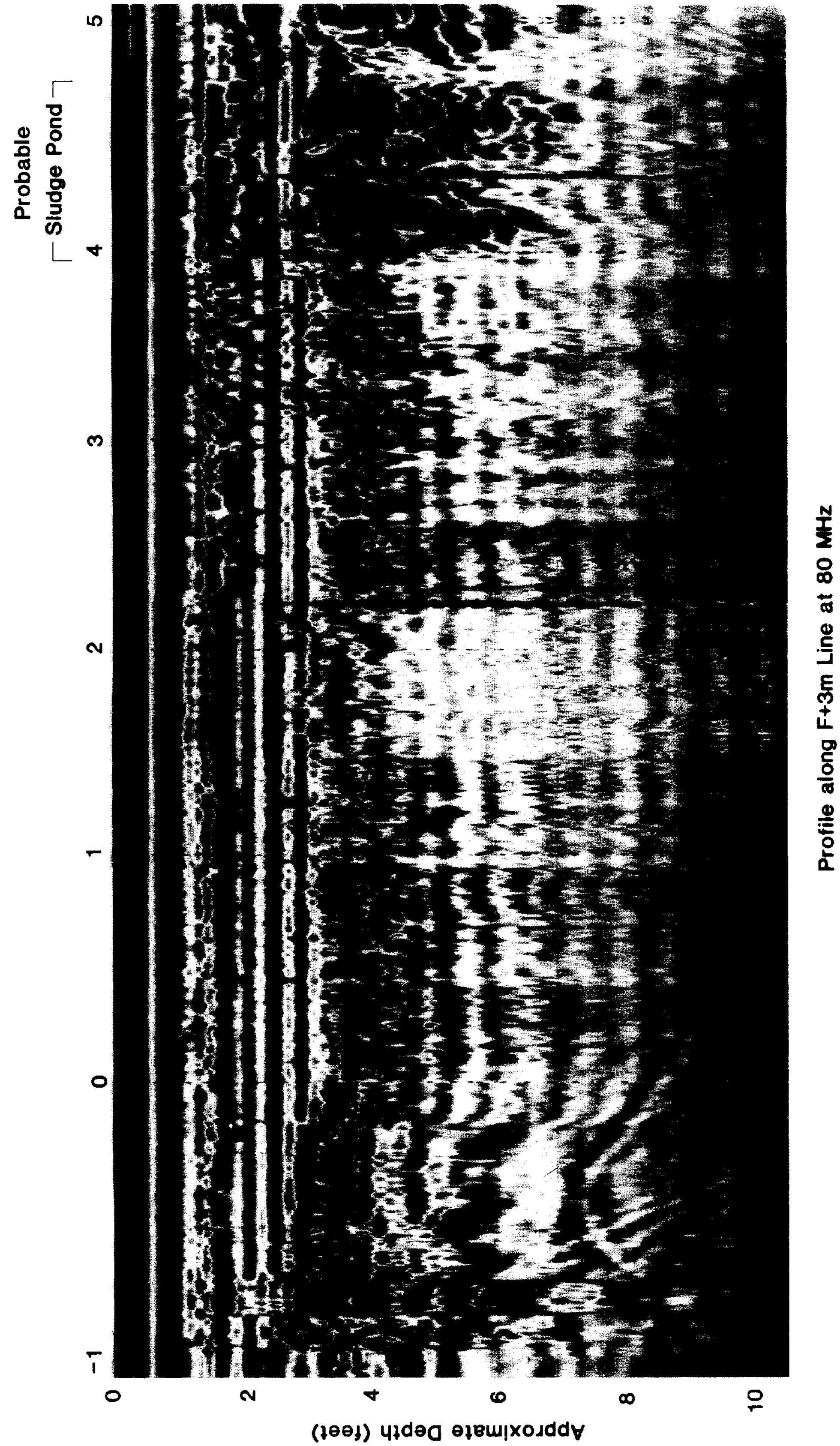


Figure 7: Radar profile along F+3
meters line.

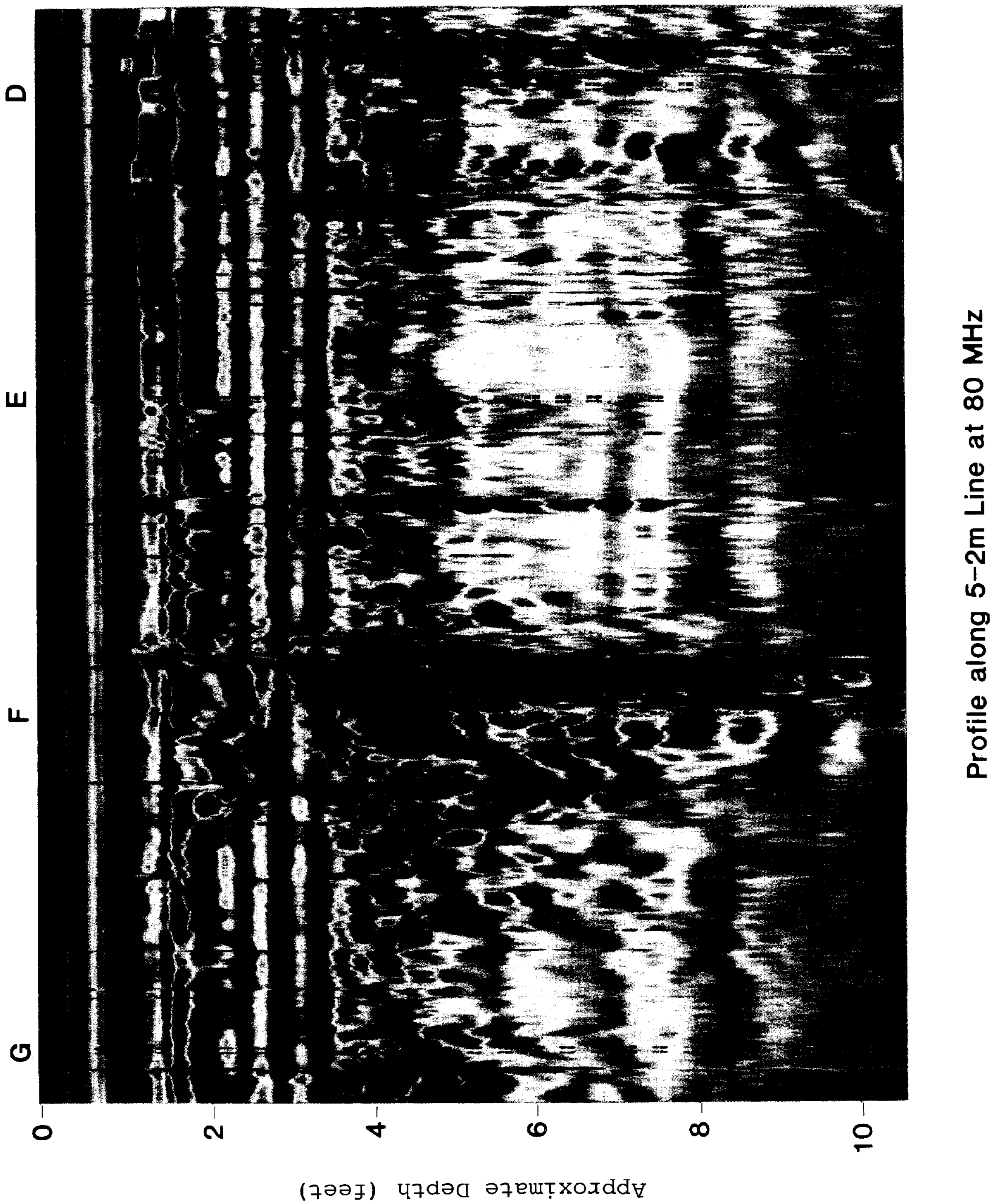


Figure 8: Radar profile along 5-2 meters line.

indicating burial activity. The region from 2+17m to 3+16m is a highly disturbed melange of numerous shallow reflectors. The scan reveals an abrupt discontinuity at about 4+00m leading into an extensive region of high reflectivity, in the midst of which a very shallow object is detectable. This zone, which continues to the end of the scan, includes an amomalous band of reduced reflectivity from 4+15m to 4+18m.

Figure 8 is a radar profile along the 5-2m line from G+2m to D-2m. A strong, continuous reflector at depth with an associated shallow disturbance extends from F+6m to F-4m, where the border is shaply defined. Portions of this zone are highly reflective. Three objects appear in the scan at E+12m, E+8m, and E+6m. The estimated depths are 3 feet 2.5 feet, and ground surface, respectively. The perturbations in the shallow ground signal just before E+00m were caused as the antenna moved over a pile of rocks.

An anomalous zone of high signal attenuation stretches from E+00m to E-5m. From D+11m to D+5m a tight cluster of scatters at depth is evident, associated with a disturbance in the shallow ground return. This suggests burial activity has occured at this location.

Figure 9 presents the zonal GPR interpretation for the W.R. Grace property. The spatial accuracy of the survey data is estimated at ± 1 meter along a scan line. Zones of anomalous radar signals are indicated.

In the burial area, the most prominant feature is located between the F, G, 4m, and 5m grid lines. This zone exhibits a very strong reflection transected by a band of diminish reflectivity. This feature may be the sludge pond indicated

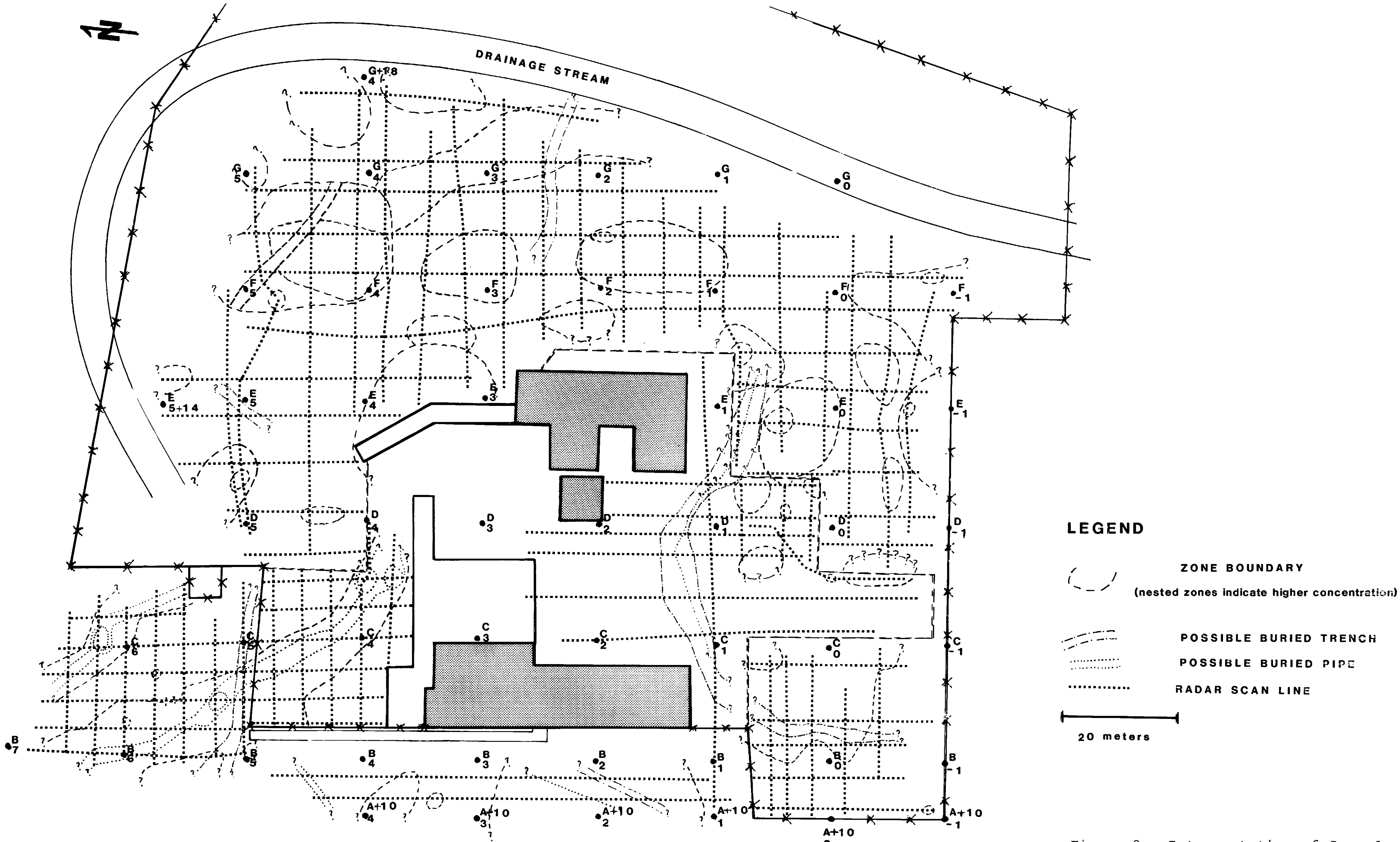


Figure 9: Interpretation of Ground-Penetration Radar Survey at the W. R. Grace Disposal Site, New Jersey.

on early maps of the site. In the parking lot areas, the main features revealed were buried pipes and catch basins with associated trenching. Particularly interestng is one which crosses the south lawn and parking area and enters the burial ground from the west.

The locations and approximate depths of detected objects are shown in Figure 10. While most appear to be randomly scattered, several zones correlate well with a high concentration of objects. The extensive zone including the coordinate G-3 and the small zone between coordinate F-2 and the building are two such examples.

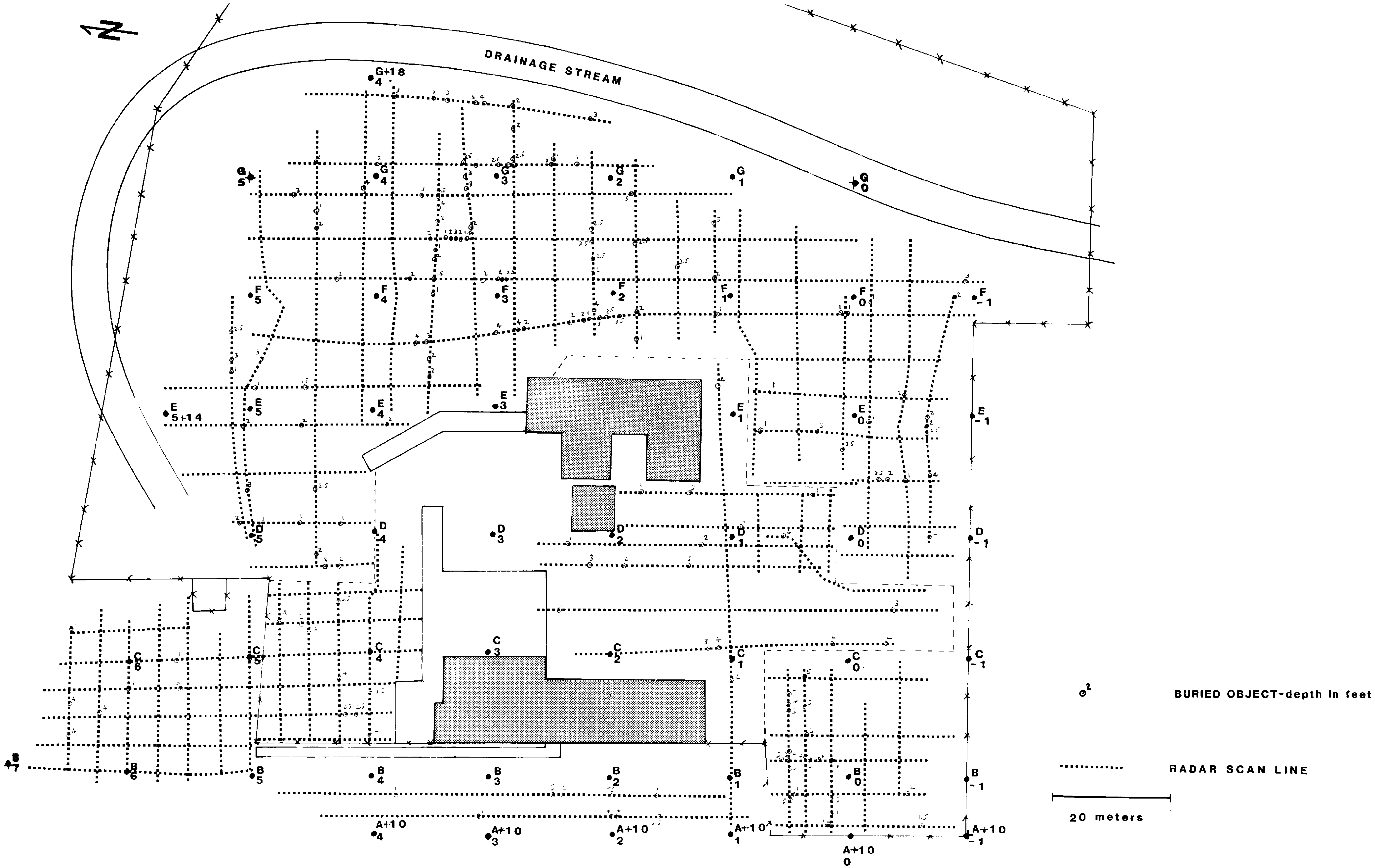


Figure 10: Map showing detected buried objects.

6. CONCLUSIONS

The interpretation of the GPR data, presented in Figures 9 and 10 has shown the W.R. Grace site to be extremely complex. The long history of burial activities, evident in the highly disturbed character of many of the GPR profiles and the profusion of buried objects detected, has produced many different anomalous zones in a small area, some of which overlap. Several of the larger zones correspond to those indicated in early reconstructed maps of the burial area.

Low values of resistivity and anomalous radar signals may be due to any or several of the following possible causes:

- Presence of metallic objects, especially pipes and conduits.
- Increased porosity and moisture content caused by disturbance of the natural soils through burial activities.
- Migration zones of electrically conductive fluids resident on site.
- Greater infiltration of runoff due to topography, etc.

With few exceptions, most of the subsurface objects were detected at an apparent depth of less than 4 feet. Their extensive, scattered distribution suggest that these materials may not have been disposed of in typical organized trenches.

In areas surveyed outside the burial ground, the only detected features were pipes and surrounding trenches. Anomalous zones in the lawn areas are probably caused by old pavement underlying the turf.

7. LITERATURE CITED

Horton, K.A., R.M. Morey, R.H. Beers, V. Jordan, S.S. Sandler, L. Isaacson, U.S. Nuclear Regulatory Commission, "Evaluation of Ground Penetrating Radar at Low-Level Nuclear Waste Disposal Sites," NUREG CR-2212, 1981.

Morey, R.M., "Continuous Subsurface Profiling by Impulse Radar," Proc. of Engineering Foundation Conference on Subsurface Exploration for Underground Excavation and Heavy Construction, American Society of Civil Engineers, 1974, pp. 213-232.

APPENDIX D

MAJOR ANALYTICAL EQUIPMENT

APPENDIX D

Major Analytical Equipment

The display or description of a specific product is not to be construed as an endorsement of that product or its manufacturer by the authors or their employer.

A. Direct Radiation Measurements

Eberline "RASCAL"
Portable Ratemeter-Scaler
Model PRS-1
Beta-Gamma "Pancake" Probe, Model HP-260
Energy Compensated G-M Probe Model HP-270
(Eberline Instrument, Santa Fe, NM)

Eberline PRM-6
Portable Ratemeter-Scaler
Scintillation Probe, Model 489-55
(Victoreen, Inc., Cleveland, OH)

Pressurized Ionization Chamber (PIC)
Model RSS-111
(Reuter Stokes, Cleveland, OH)

Ludlum Ratemeter-Scaler
Model 2200
(Ludlum Measurements Inc., Sweetwater, TX)

B. Laboratory Analysis

Ge(Li) Detector
Model LGCC2220SD, 23% efficiency
(Princeton Gamma-Tech, Princeton, NJ)

Used in conjunction with:
Lead Shield, SPG-16
(Applied Physical Technology, Smyrna, GA)

Pulse Height Analyzer, ND680
Model 88-0629
(Nuclear Data, Inc., Schaumburg, IL)

Alpha Spectroscopy System
Tracor Northern 1705
Pulcir PA-1 Alpha Module
(Pulcir, Inc., Oak Ridge, TN)

Low Background Alpha-Beta Counter
Model LB5100-2080
(Tennelec, Inc., Oak Ridge, TN)

25 mg Californium-252 Source with Flexo-Rabbit
Pneumatic Transfer System
(Reactor Experiments, Inc., San Carlos, CA)

Multichannel Analyzer
Model TN-7200
(Tracor Northern, Middleton, WI)

APPENDIX E

ANALYTICAL PROCEDURES

APPENDIX E

Analytical Procedures

Gamma Scintillation Measurments

Walkover surface scans and measurements of gamma exposure rates were performed using an Eberline PRM-6 portable ratemeter with a Victoreen Model 489-55 gamma scintillation probe containing a 3.2 cm x 3.8 cm NaI(Tl) scintillation crystal. A graph of count rate (cpm) vs. exposure rate (μR/h) was developed by comparing the response of the scintillation detector with that of a Reuter Stokes Model RSS-111 pressurized ionization chamber at several locations on and off the W.R. Grace property. This plot was used to convert the meter readings to exposure rates.

Additional Exposure Rate Measurements

Exposure rates at several locations on the property exceeded the measuring range of the gamma scintillation equipment. At those locations, exposure rates were measured using Eberline energy compensated Model HP-270 G-M probes with Eberline "Rascal" Model PRS-1 portable ratemeters. Calibration of this instrumentation was by cross reference to a Reuter-Stokes Model RSS-111 pressurized ionization chamber.

Beta-Gamma Dose Rate Measurements

Measurements were performed using Eberline "Rascal" Model PRS-1 portable ratemeters with Model HP-260 G-M probes. Dose rates (μrad/h) were determined by comparison of the response of a Victoreen Model 440 ionization chamber survey meter to that of the G-M probes for a natural thorium source.

Borehole Logging

Borehole gamma radiation measurements were made using a Victoreen Model 489-55 gamma scintillation probe connected to a Ludlum Model 2200 portable scaler. The scintillation probe was shielded by a 1.25 cm thick lead shield with four 2.5 cm x 7 mm holes evenly spaced around the shield in the region of the scintillation detector. The probe was lowered into each hole using a tripod holder with a small winch. Measurements were performed at 30 cm intervals in all holes.

Because of varying ratios of thorium, uranium, and radium noted on the site no attempt was made to use the borehole logging data to directly estimate subsurface thorium soil concentrations. The borehole logging data was used to identify regions of elevated residues and thus guided the selection of subsurface soil sampling locations.

Soil and Sediment Sample Analysis

Soil and sediment samples were sifted to remove rocks (the fraction removed constituted <5% of the total), dried at 120° C, finely ground, mixed, and a portion placed in a 0.5 liter Marinelli beaker. The quantity placed in each beaker was chosen to reproduce the calibrated counting geometry and typically ranged from 500 to 800 g of soil. Net weights were determined and the samples counted using a 23% Ge(Li) detector (Princeton Gamma Tech) coupled to a Nuclear Data model ND 680 pulse height analyzer. The following energy peaks were used for determination of the radionuclides of concern:

Th-232	- 0.911 MeV from Ac-228	(secular	equilibrium	assumed)
Th-228	- 0.583 MeV from Tl-208	"	"	"
Ra-226	- 0.609 MeV from Bi-214	"	"	"
U-238	- 1.001 MeV from Pa-234m	"	"	"

Peak identification and concentration calculations were provided by computer analyses.

Samples for which gamma spectrometry indicated detectable levels of uranium were subsequently analyzed for U-238 by neutron activation. Approximately 15-20 g of soil were irradiated for 15 minutes in a neutron flux of 10^8 n/cm^2/sec. After a one minute wait time, the U-239 peak (74.6 keV) was counted for 10 minutes and the U-238 concentration calculated.

Water Samples

Water samples were rough filtered through Whatman No. 2 filter paper. Remaining suspended solids were removed by filtration through 0.45 μm pore size membrane filters. The filters, together with attached solids, were discarded, and the filtrate was acidified by the addition of 20 ml of concentrated nitric acid.

Gross Alpha and Gross Beta Analysis

Fifty milliliters of each sample was evaporated to dryness and counted on a Tennelec Model LB5100 low background proportional counter.

Radium-226/228 Analysis

Samples were analyzed for Ra-226 and 228 using the standard technique EPA 600/4-75-008 (Rev.)

Vegetation Analysis

Gamma Spectrometry

After being washed vegetation samples were air dried, chopped, and mixed. Aliquots were placed in 3.5 ℓ Marinelli beakers and analyzed for identifiable photopeaks in the same manner described above for soil sample analysis. Due to possible preferential uptake and assimilation of various radionuclides by vegetation, it could not be assumed that Th-232 and Ra-228 were in equilibrium. Therefore, Ra-228, rather than Th-232, concentrations are reported for vegetation samples.

Errors and Detection Limits

The errors, associated with the analytical data presented in the tables of this report, represent the 95% (2σ) confidence levels for that data. These errors were calculated, based on both the gross sample count levels and the associated background count levels. When the net sample count was less than the 2σ statistical deviation of the background count, the sample concentration was reported as less than the minimum detectable activity (<MDA). This means that the radionuclide was not present, to the best of our ability to measure it, utilizing the analytical techniques described in this appendix. Because of variations in background levels, caused by other constituants in the samples, the MDAs for specific radionuclides differ from sample to sample.

Calibration and Quality Assurance

Laboratory analytical instruments are calibrated using NBS-traceable standards. Portable survey instruments for exposure rate and dose rate measurements are calibrated by comparison of their responses to those of other instruments having NBS-traceable calibration. Field comparisons or comparisons using samples typical of the area are used to develop these calibrations.

Quality control procedures on all instruments included daily background and check-source measurements to confirm lack of malfunctions and nonstatistical deviations in equipment. The ORAU Laboratory participates in the EPA Quality Assurance Program.